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Hydrocomp, Inc.
Mountain View, CA

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EXECUTIVE SUMMARY
FOR THE
HYDROLOGICAL SIMULATION PROGRAM - FORTRAN
(HSPF)

by

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16. ABSTRACT

This executive summary introduces water resource managers, engineers, and programmers to the Hydrological Simulation Program--FORTRAN and provides them with information that can help them in deciding whether HSPF would be useful and practical for them to use. HSPF uses digital computers to simulate hydrology and water quality in natural and man-made systems. Although data requirements are extensive and running costs are significant, HSPF is thought to be the most accurate and appropriate management tool presently available for the continuous simulation of hydrology and water quality in watersheds.

The summary begins with a general overview of the model, how it compares with other models, and how it can be applied. For those more interested in technical details, the summary follows with detailed information on the model's input requirements, capabilities, innovative features and design criteria. This latter information should be of particular interest to those acquainted with simulation models, who can appreciate the advanced programming techniques used to develop HSPF.

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FOREWORD

As environmental controls become more costly to implement and the penalties of judgment errors become more severe, environmental quality management requires more efficient analytical tools based on greater knowledge of the environmental phenomena to be managed. As part of this Laboratory's research on the occurrence, movement, transformation, impact, and control of environmental contaminants, the Technology Development and Applications Branch develops management and engineering tools to help pollution control officials achieve water quality goals through watershed management.

The development and application of mathematical models to simulate the movement of pollutants through a watershed and thus to anticipate environmental problems has been the subject of intensive EPA research for several years. The most recent advance in this modeling approach is the Hydrological Simulation Program--FORTRAN (HSPF), which uses digital computers to simulate hydrology and water quality in natural and man-made water systems. HSPF is designed for easy application to most watersheds using existing meteorologic and hydrologic data. Although data requirements are extensive and running costs are significant, HSPF is thought to be the most accurate and appropriate management tool presently available for the continuous simulation of hydrology and water quality in watersheds.

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ABSTRACT

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The summary begins with a general overview of the model, how it compares with other models, and how it can be applied. For those more interested in technical details, the summary follows with detailed information on the model's input requirements, capabilities, innovative features and design criteria. This latter information should be of particular interest to those acquainted with simulation models, who can appreciate the advanced programming techniques used to develop HSPF.

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SECTION 1
INTRODUCTION

INTRODUCTION TO HSPF

The Hydrological Simulation Program-FORTRAN (HSPF) is a mathematical model developed under EPA grant No. R804971-01. HSPF was designed for use on digital computers to simulate hydrologic and water quality processes in natural and man-made water systems. It is an analytical tool that has application in the planning, design, and operation of water resources systems. The model enables the use of probabilistic analysis in the fields of hydrology and water quality management. To simulate the processes that occur in a watershed, HSPF uses such information as the time history of rainfall, temperature, and solar intensity and the parameters related to land use patterns, soil characteristics, and agricultural practices. The initial result of an HSPF simulation is a time history of the quantity and quality of water transported through various soil zones down to the groundwater aquifers. Runoff flow rate, sediment loads, nutrients, pesticides, toxic chemicals and other quality constituent concentrations can be predicted. The model then takes these results and information about the receiving water channels in the watershed and simulates the processes that occur in these channels. This part of the simulation produces a time history of water quantity and quality at any point in the watershed.

HSPF is an extension and improvement of three previously developed models: 1) The Agricultural Runoff Management (ARM) Model, a non-proprietary program written in FORTRAN (1); 2) The Non-Point Source Runoff (NPS) Model, also a non-proprietary program written in FORTRAN (2,3); and 3) The Hydrologic Simulation Program (HSP, including HSP Quality), a Hydrocomp proprietary program written in PL1. The EPA recognized several years ago that the continuous simulation approach contained in these models would be valuable in solving many complex water resource problems. Thus, a fairly large

investment was devoted to developing a highly flexible non-proprietary FORTRAN program that contains the capabilities of these three models, plus many extensions. The result of this investment is HSPF. It is geared to the serious user; one who understands continuous simulation modeling, and can make use of the flexibility that it provides.

HSPF PHILOSOPHY

Management of water resources involves the commitment of other resources to protect and develop our water. This commitment may range from construction of facilities to the non-use of undeveloped land. Such commitments can only be justified when one knows the benefits or effectiveness of the protection to be achieved. A fundamental question in benefit evaluation is whether an undesirable water quality event occurs once a month, once a year, or once a decade.

Information on hydrologic or water quality events cannot be used effectively for water resources planning unless the probability of occurrence of the events is known. The occurrence of a water quality event is strongly conditioned by antecedent events. As an example, the current population of phytoplankton in a lake is a function of the phytoplankton, zooplankton, and nutrient population yesterday. Likewise, the population of phytoplankton five days ago has a small but finite effect upon the current population of phytoplankton.

Though it is reasonable to assume the physical, chemical, and biological laws that govern interactions in a body of water are invariant, specific reaction rates are determined by what is in the water body and by the stresses imposed upon the water body by inflows. These inflows can be man-caused flows such as wastewater discharges and irrigation return flow, or natural flows such as runoff from rainfall and snowmelt. Natural flows

are governed by the climate, soil type, vegetal cover, and other physical features of the watershed. Since vegetal cover (forests, grassland) and human activity (land development, channelization, and reservoirs) can, and often do, change rapidly over short periods of time, they too must be considered variables in water resource planning. Thus, the only constants in water resources planning are the physical, chemical, and biological laws of nature, and the soil types and other fixed physical characteristics of the watershed.

Planners need a method to determine the frequency characteristics of the hydrology and water quality of a watershed under alternative plans for future development. This need led to the development of continuous dynamic simulation, the simulation of extended time periods with varying flows and meteorologic conditions. From five to more than one hundred years of data may be required to adequately determine the statistics for streamflow and water quality constituents. Simulation of a "critical period" cannot provide the information necessary to determine the probability of water quality events. In fact, the critical period itself might change from one wastewater management scheme to the next. Hence, HSPF simulation deals with the total process, hydrologic and bio-chemical, as a continuous process in time.

The use of probability information for the physical and economic evaluation of both flood control and water supply plans is well established (4,5,6). As an example, the approach for flood control analysis requires the determination of streamflow frequency curves under existing conditions and under a proposed flood control plan (Figure 1). Combining the streamflow frequency curves with derived or measured streamflow (or stage) damage curves allows the development of flood damage frequency curves (Figure 2) for existing conditions, and with a flood control plan assumed to be in effect. The difference in area beneath the two curves in Figure 2 represents the expected average annual benefits from the proposed plan as

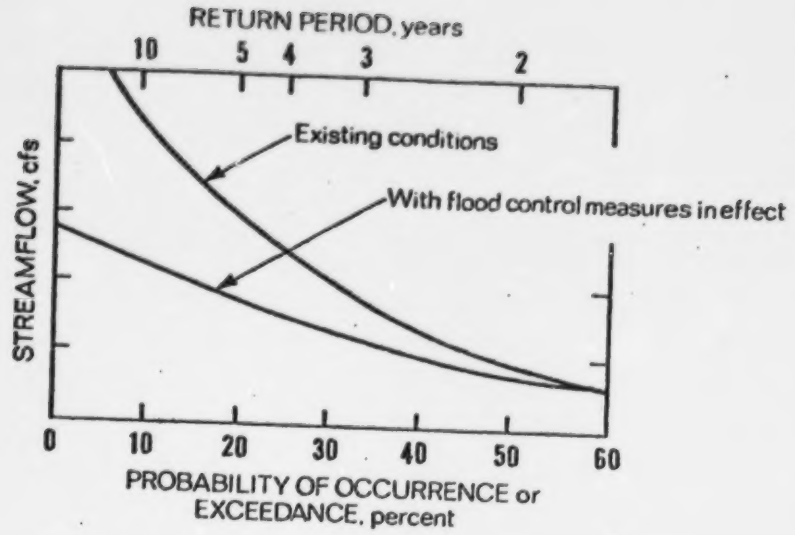

Figure 1 Streamflow frequency curve

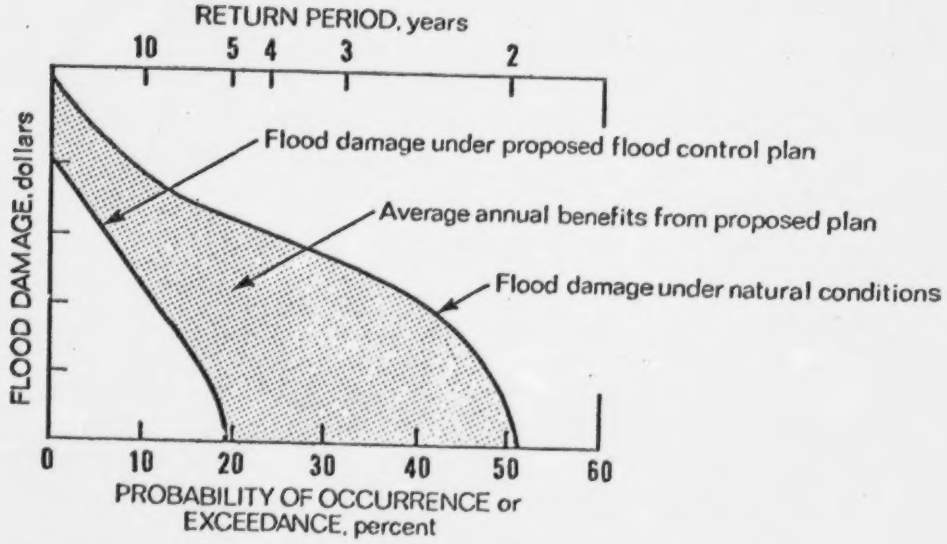

Figure 2 Flood damage-frequency curve

measured by the reduction in damages. The damage calculations from Figure 2 are graphical representations of concepts from elementary decision theory, where the expected value of an alternative equals the consequences (damages) of a particular event times its probability of occurrence, summed over all possible events (7). With the use of probability information, we can specify from Figure 1 the degree of protection provided by a proposed plan and from Figure 2 the expected benefits. The economic evaluation can then proceed by comparing the calculated benefits with the associated costs.

In applying these techniques, a hydrologist would prefer to have a long record of historic streamflow data at the proposed site to reliably establish the existing streamflow frequency curve. In most situations, such data are not available. Moreover, the effects of urban development and other watershed changes can bias major portions of a historic record. Continuous simulation can be used to develop long records of streamflow for the existing conditions and for the flood control plan. A simulation model can be adjusted (calibrated) to represent the watershed characteristics by using a short streamflow record (3 to 5 years) with little change in land use conditions. Long-term meteorologic data are input to the model to obtain a simulated streamflow record of equal length from which the streamflow frequency curve can be determined. Repeating the procedure with the model adjusted to represent the proposed flood control plan will produce a modified frequency curve. The application of continuous simulation has been demonstrated in numerous flood control and drainage studies (8,9,10).

Probability information has not been as extensively used for water quality management as for flood control and water supply analysis. The main reasons for this are the general lack of historic water quality data as a basis for probability analysis and a lack of data on the damage (or costs incurred) because of pollution. The procedure is analogous to that described above for flood control and has been discussed by Donigian and Waggy (11), based on concepts presented by Kneese (12) and James and Lee (13). Pollutant

concentration frequency curves (Figure 3) are derived for existing conditions and for the proposed water quality management plan. With the use of relationships between pollutant concentration and water quality damages (Figure 4), damage frequency curves (Figure 5) can be developed from which the average annual benefits of the water quality control plan are determined.

The major problems in application of this methodology pertain to the development of the relationships shown in Figures 3 and 4. Figure 4 is derived from economic considerations; the pollutant concentration frequency curves in Figure 3 can be obtained from continuous water quality simulation. In most instances, this is the only way continuous water quality information can be obtained.

COMPARISON OF HSPF TO OTHER MODELS

Numerous hydrologic and water quality models are available. It is important to point out some of the differences between HSPF and these other models. Many of the differences are shown in Table 1, which summarizes the basic capabilities of HSPF and several other models. A brief description of the models is given below.

The Agricultural Runoff Management (ARM) model, Non-point Source (NPS) model, and Hydrologic Simulation Program (HSPX) are all predecessors of HSPF as mentioned above. The Stormwater Management Model was designed to simulate flows and water quality on urban areas and open channels. It can handle flows through complex sewer networks, and in tidally influenced non-stratified estuarine areas.

QUAL II is a quasi-dynamic model that simulates flows and water quality conditions in free flowing streams. The word "quasi-dynamic" is used since

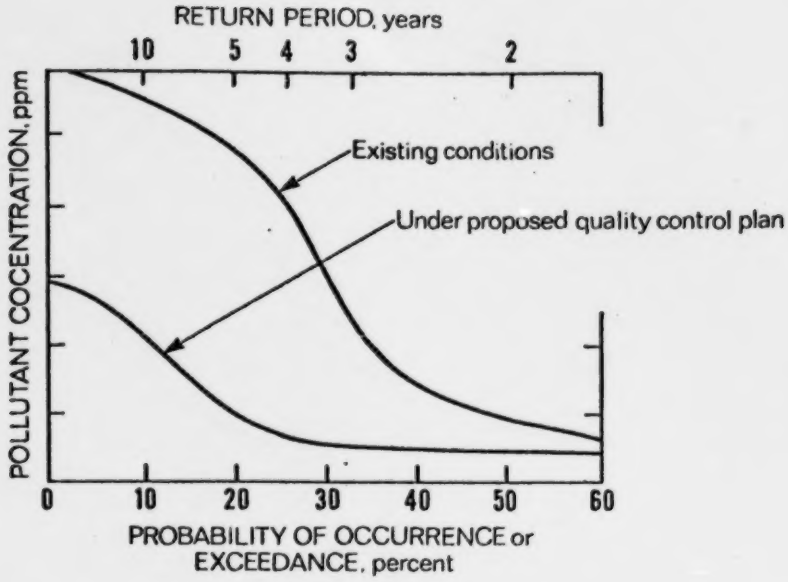

Figure 3 Pollutant concentration-frequency curve

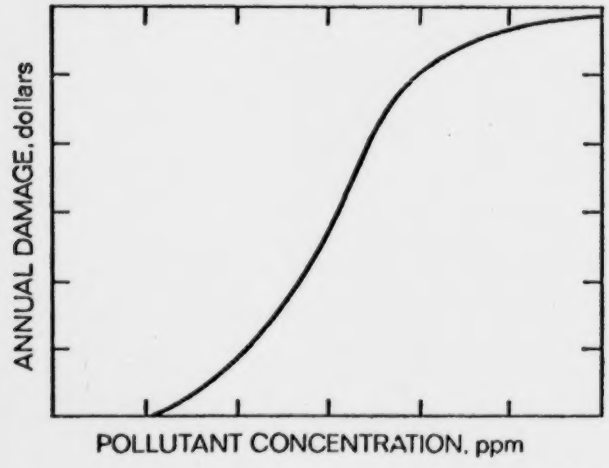

Figure 4 Damage-concentration curve for a specific pollutant

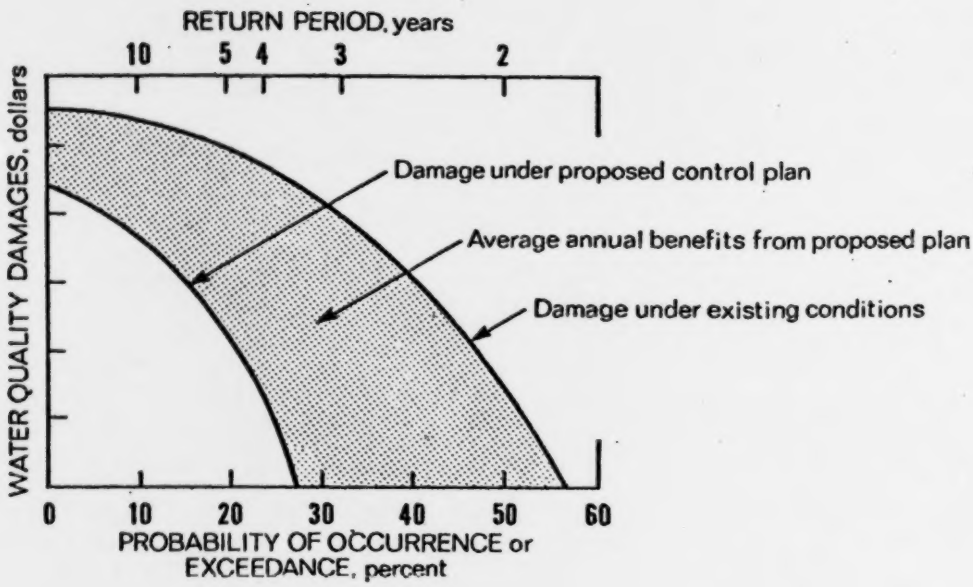

Figure 5 Water quality damage-frequency curve

TABLE 1
MODEL CAPABILITIES COMPARISONS

	LAND SURFACE SIMULATION CAPABILITIES					"CHANNELS" SIMULATION CAPABILITIES			
	HYDROLOGY			WATER QUALITY		HYDRUALICS			
MODELS	PERVIOUS LANDS	IMPERVIOUS LANDS	SNOWMELT	PHYSICAL/ CHEMICAL CONSTIT.	AGRICULTURAL CHEMICALS	1 DIMENSIONAL STREAMS	UNSTRATIFIED RESERVOIRS	STRATIFIED RESERVOIRS	ESTUARIES
HSPF	●	●	●	●	●	●	●		
ARM	●		●	●	●				
NPS	●	●	●	●					
HSPX	●	●	●	●		●	●	●	
SWMM		●		●		●	●		●
QUALII						●			
SSARR	●	●	●			●	●		
USDAHL	●	●				●			
MIT MODEL	●	●	●			●			
STORM	●	●	●	●					

TABLE 1
MODEL CAPABILITIES COMPARISONS
(cont.)

	"CHANNELS" SIMULATION CAPABILITIES					POSSIBLE RUN MODES					
	WATER QUALITY					STEADY STATE		DYNAMIC EVENT		CONTINUOUS	
MODELS	BASIC PARA-METERS	SEDIMENTS	NUTRIENTS	ALGAE	PH	HYDROLOGY	WATER QUALITY	HYDROLOGY	WATER QUALITY	HYDROLOGY	WATER QUALITY
HSPF	●	●	●	●	●	●	●	●	●	●	●
ARM						●	●	●	●	●	●
NPS						●	●	●	●	●	●
HSPX	●		●	●	●	●	●	●	●	●	●
SWMM	●		●			●	●	●	●		
QUALII	●		●	●		●	●				
SSARR						●		●		●	
USDAHL						●		●		●	
MIT MODEL						●		●			
STORM	●		●			●	●	●	●		

streamflows and waste sources are only considered as constants in time.

The Streamflow Synthesis and Reservoir Regulation (SSARR) Model was developed by the Army Corps of Engineers, North Pacific Division to simulate flows of the Columbia River System. The primary objective of the model was the analysis of reservoir regulation and streamflow forecasting on large watersheds.

The United States Department of Agriculture Hydrograph Laboratory (USDAHL) model was developed by USDA to study the effects of agricultural activities on hydrology. The 1970 version of the model does not include sediment and water quality simulation. However, it has potential for adding these algorithms.

The MIT urban watershed model simulates time varying flows on lands, sewer networks, and open channels. It was designed primarily for simulation of urban catchment areas.

The Storage, Treatment and Overflow Model (STORM) was developed by the Corps of Engineers, Hydrologic Engineering Center, to evaluate the stormwater runoff and water quality characteristics of a single urgan catchment area. This model does not handle dry-weather conditions and, thus, cannot be used in a continuous simulation mode.

As shown in Table 1, HSPF is generally more comprehensive and flexible than all the other models shown. It includes all the capabilities of the three of its predessessors (ARM, NPS and HSPX) except for the stratified reservoir options of HSPX. In addition, HSPF has unique data handling capabilities that make it possible to simulate many land segments of a large watershed, which is not possible with ARM, NPS, and most of the other models. The data handling routines in HSPF also make it relatively easy to link with a

stratified reservoir or estuarine model.

Why are continuous models an improvement over dynamic event models? The long-term probabilistic character of hydrology and water quality, as discussed earlier, is only available from continuous models. The magnitudes and recurrence intervals of certain harmful events cannot be predicted using event models. One common mistake is that rainfall events of given recurrence intervals are assumed to result in streamflow and flood conditions of the same recurrence interval (i.e. the 25 year rainfall event leads to a 25 year flood). This assumption is erroneous due to factors such as snowmelt and soil water storage, that modify the statistics of rainfall as the water flows on the land and river channels. The use of this invalid assumption in using event models commonly leads to inappropriate planning conclusions.

SECTION 2
MODEL EVALUATION AND OPERATION

HSPF APPLICATIONS

HSPF is probably the most comprehensive and flexible model of watershed hydrology and water quality available today. It is the only available model that can simulate the continuous, dynamic event or the steady-state behavior of both hydrologic/hydraulic and water quality processes in a watershed. The model is also unusual in its ability to represent the hydrologic regimes of a wide variety of streams and rivers with reasonable accuracy. Thus, the potential applications and uses of the model are comparatively large as shown in Table 2.

MODEL SELECTION

The decision of whether to use a model, and which model to use is an important part of water resource plan formulation. some general guidelines in selecting a particular simulation tool for a specific water resource problem.

> "Mathematical simulation based on equations of physical processes is a relatively new tool that has become available to the water quality planner. Its usefulness depends on his ability to obtain sufficient data that can be used to calibrate and verify the model and carry out the desired simulation experiments. The planner may have to decide whether an existing model would be appropriate or whether a new one should be developed. He should estimate the cost and effort associated with the use of computer models, make

Table 2

HSPF APPLICATIONS

MODULE	PROBLEM APPLICATIONS
Hydrologic & Hydraulic Modules	1) Flood mapping 2) Planning for flood control measures 3) Hydropower studies and design 4) Hydropower operations scheduling 5) River basin planning 6) Urban Drainage studies 7) Groundwater studies 8) Watershed diversion studies 9) Educational tool
Water Quality Modules	1) Study of waste treatment strategies 2) Study of agricultural pollutant runoff and control strategies 3) Study of toxic substances on land and control strategies 4) Study of urban non-point pollutant sources 5) Study of water quality in streams and non-stratified reservoirs 6) Study of sedimentation and erosion problems 7) Study of the effects of diversions, flood control projects and other channel alterations on in-stream water quality. 8) Study of long-term water quality trends 9) Educational tool

comparisons with all other suitable methods of approach, and take into account the quality and extent of information he can obtain from alternative approaches. If he determines that a model should be used, then his task is to determine which model is most appropriate for his planning problem. Although the use of computer simulations requires a highly organized approach to planning, it enables the study of a range of alternatives that might otherwise be beyond the scope of study by other methods due to cost.

While no clear-cut rule can be formulated regarding the use of simulation models as planning tools, a few simple guidelines can be stated on the basis of the analysis presented so far in this manual. The guidelines should not be interpreted as strict rules, but rather as broad statements that are meant to serve as reminders. Their validity as guidelines will probably be demonstrated by the frequency with which they are violated. The list is left open ended; additions, deletions, or modifications will be necessary as experience is gained in the use of models for planning.

1. The first step is to define the problem and determine both what information is needed and what questions need to be answered.

2. Use the simplest method that can provide the answers to your questions.

3. Use the simplest model that will yield adequate accuracy.

4. Do not try to fit the problem to a model, but select a model that fits the problem.

5. Do not confuse complexity with accuracy.

6. Always question whether increased accuracy is worth the increased effort and cost.

7. Do not forget the assumptions underlying the model used, and do not read more significance into the simulation results than is actually there."

In light of these comments it is apparent that HSPF is not the best planning tool for all water resource problems. Its capabilities may be far greater than those necessary for many problems such as: 1) examining steady-state or "event" conditions 2) focusing only on a small part of a watershed such as a reservoir or a single stretch of stream 3) focusing only on a specific hydrologic process or water quality condition. A model tailored to the specific problem at hand may be more cost-effective than a generalized, all-purpose model such as HSPF.

The algorithms contained in HSPF, as with all other models, contain simplifications relative to the real world that limit its use for certain situations. For example, channel hydraulics are limited to uni-directional (downstream) flow; thus limiting its ability to represent tidal and backwater conditions. The reservoir module does not presently account for vertical stratification which is common in large reservoirs (this capability would not be difficult to add). Although most of the HSPF algorithms used to simulate water quality constituents are considered "state-of-the-art," they are laced with simplifying assumptions. Those algorithms of interest to

the user should be examined carefully in the "Users Manual" and compared with those of other models to ensure that HSPF is the best model to use.

HSPF was designed so that it could be easily applied to most watersheds using existing meteorologic and hydrologic data. Indeed, the inputs required by HSPF are not different than those needed by most other simpler models. The primary difference in data needs is that long rather than short time-series records are needed (when the continuous simulation capability of the program is exercised) for the pertinent time-varying inputs such as precipitation and waste-discharges and calibration data such as streamflow and constituent concentrations. Such data do not always exist. Such data limitations may warrant the use of a simpler simulation approach.

Funding limitations may also play an important part in the selection of a simulation tool. Although computational costs are continually decreasing, HSPF running costs are significant. Several hundred dollars could be spent on a single production run of a large watershed. Funds are also needed to set up the program and input decks, and for model calibration. The funds needed for a successful HSPF application are dependent on many factors, but in most cases are of the order of tens of thousands of dollars.

In conclusion, for applications where continuous simulation of hydrology and/or water quality is desired, and where data availability and project funds are not major problems, HSPF is probably the most accurate and appropriate simulation tool available, and should be considered seriously.

OPERATION OF HSPF

Users Control Input

HSPF is operated by supplying the User's Control Input (UCI), which specifies the type of simulation operations to be run, directs the flow of time series between data files and the operations, and provides parameters and initial conditions applicable to each operation. The structure of the UCI is discussed briefly in Section 8. Detailed documentation on the UCI is given in the HSPF User's Manual (14).

Inputs Listing

Tables 3 and 4 give a concise listing of the inputs required by the various HSPF modules. These tables show which inputs are needed in time series form, which are given as constants, and which can be given as constants that vary on a monthly basis. These tables do not include the initial conditions data. In particular, the storages of water and quality constituents (those modelled) at the beginning of the simulation period must be provided. Usually, the accuracy of the initial conditions is not critical since errors in initial condition inputs will damp out as the simulation proceeds. (Note: This is another major advantage of continuous simulation as opposed to event models that often rely heavily upon the initial conditions data) Not all the inputs listed in Tables 3 and 4 are needed for every HSPF run. The particular inputs required depend on which modules and water quality constituents are run, and which options in the various modules are used. Part F of the User's Manual provides the details of which inputs are required under specific program running conditions.

TABLE 3
INPUTS FOR HYDROLOGY AND HYDRAULICS
SECTIONS OF HSPF

TIME SERIES INPUTS

air temperature[1]
precipitation
dewpoint temperature[1]
wind movement[1]
solar radiation[1]
potential evapotranspiration
channel inflows not simulated
channel diversions
surface lateral inflow to land segment[2]
interflow lateral inflow to land segment[2]
groundwater lateral inflow to land segment[2]

[1]Needed only if snow module is used, or for water quality modules.

[2]These inputs are optional. If entire watershed is modeled, these can usually be assumed to be zero.

CONSTANT PARAMETER INPUTS

Interception storage (maximum value)
Nominal upper zone soil moisture storage
Nominal lower zone soil moisture storage
Infiltration index
Interflow index
Areal cover of deep-rooted vegetation
Seepage to deep (or inactive) groundwater
Evaporation from groundwater within reach of vegetation
Length of overland flow (feet)
Overland flow slope
Manning's "N" for overland flow (constant or monthly)
Daily interflow recession rate
Daily groundwater recession variable rate
Exponent of the infiltration curve equation
Actual upper zone soil moisture storage at start
Actual lower zone soil moisture storage
Groundwater storage volume
Groundwater slope parameter
Surface detention storage
Interflow detention storage
Interception storage volume
Convection-condensation melt parameter
Snow correction factor
Elevation difference in thousands of feet
Index density of new snow
Forest cover index
Daily ground melt
Water content of snow at saturation (fraction)
Water equivalent of snow-pack for complete areal coverage
Channel geometry
Stage discharge relationships
Channel slope
Ratio of max and mean velocities in channels
Retention (interception) storage capacity of impervious surface (constant or monthly)

TABLE 4
INPUTS TO WATER QUALITY
SECTIONS OF HSPF
(cont.)

REACH AND RESERVOIR WATER QUALITY, (cont.)

Benthal oxygen demand rate - constant
Benthal release of BOD - constant
Reaeration characteristics and coefficients - constants
Content of carbon, oxygen, nitrogen and phosphorus in biomass - constants
Nitrogen and phosphorus benthic release rates - constants
Oxidation rates of ammonia and nitrate - constants
Chlorophyll "A" content of biomass - constant
Fraction of algae and Zooplankton biomass - constant
Light extinction coefficients - constants
Maximal algal growth rate - constant
Constants for light nitrogen and phosphorus limited growth - constants
Temperature thresholds for algal growth retardation - constants
Algal respiration rate - constant
High and low algal death rate - constant
Phytoplankton death rate due to anerobic conditions - constant
Lower thresholds of nitrogen and phosphorus concentrations below which high algal death occurs - constants
Advective characteristics of plankton - constants
Threshold of chlorophyll "A" concentration above which high algal death occurs- constant
Phytoplankton settling rate - constant
Dead refractory organics settling rate - constant
Maximum zooplankton ingestion rate - constant
Zooplankton filtering rate - constant
Zooplankton respiration rate - constant
Natural zooplankton death rate - constant
Increment of zooplankton death rate due to anaerobic conditions - constant
Average weight of zooplankton organism - constant
Maximum benthic algae density
Ratios of benthic algal to phytoplankton respiration and growth rates - constants
CO_2 invasion rate at water surface - constant
Benthal release of CO_2 - constant
Meteorological time series listed in inputs for hydrology - time series
Inflow concentrations of all simulated constituents - time series

TABLE 4
INPUTS TO WATER QUALITY
SECTIONS OF HSPF
(cont.)

AGRICHEMICAL QUALITY CONSTITUENTS, (cont.)

Pesticide degradation rates (each layer) - constant
Nitrogen plant uptake rates (each layer) - constant or monthly
Fraction of plant uptake from NO_3 and NH_4 - constant
Temperature correction coefficients for various nitrogen reactions - constant
Ammonium desorption rate (each layer) - constant
Ammonium adsorption rate (each layer) - constant
Nitrate immobilization rate (each layer) - constant
Organic N ammonification rate (each layer) - constant
Dentrification rate (each layer) - constant
Nitrification rate (each layer) - constant
Ammonium immobilization rate (each layer) - constant
Max. solubility of ammonium - constant
Nitrogen adsorption-desorption parameters (each layer) - constant
Phosphorus plant uptake rates (each layer) - constant or monthly
Temperature correction coefficients for various phosphorus reactions - constant
Phosphate desorption parameters (each layer) - constant
Phosphate adsorption parameters (each layer) - constant
Phosphate immobilization rate (each layer) - constant
Organic P minieralization (each layer) - constant
Max. solubility of phosphate (each layer) - constant

IMPERVIOUS LAND WATER QUALITY

Solids washoff coefficient and exponent - constant
Rate of solids placement on surface - constant or monthly
Rate of solids removal on surface - constant or monthly
Ground elevation - constant
Air temperature to surface water temp. recession constants - constant or monthly
Sediment borne pollutant washoff potency factor (each const.) - constant or monthly
Overland flow borne pollutant accumulation rate (each const.) - constant or monthly
Overland flow born pollutant max. storage (each const.) - constant or monthly
Surface runoff removal rate (each const.) - constant or monthly
Lateral input of sediment to segment surface - time series (optional)

REACH AND RESERVOIR WATER QUALITY

Solar radiation correction factor - constant
Longwave radiation coefficient - constant
Conduction convection heat transport coefficient - constant
Evaporation coefficient - constant
Washload material sinking rate - constant
Sandload suspension coefficient and exponent - constants
Decay coefficients for 1st order decay constituents - constants
Temp. correction for 1st order decay coefficients - constants
BOD Benthic release characteristics and rates - constants
BOD decay rate and temperature correction - constants
BOD settling rate - constant
Allowable level of DO supersaturation - constant

TABLE 4
INPUTS TO WATER QUALITY
SECTIONS OF HSPF

LAND SEDIMENT

Supporting management practice factor - constant
Soil Detachment coefficient and exponent - constants
Rate of soil re-attachment - constant
Land surface cover - constant or monthly
Sediment influx from atmosphere - constant or monthly
Detached sediment washoff coefficient and exponent - constant
Matrix soil scour coefficient and exponent - constant
Lateral input of sediment to segment surface - time series (optional)

SOIL TEMPERATURE

Slope and intercept of land surface temp to air temp equation - constants
Smoothing factors in temperature calculations - constants
Lower zone soil temperatures - monthly
Air temperature - time series

DISSOLVED GAS IN LAND WATERS

Ground elevation - constant
Interflow and Groundwater concentration of DO - constant or monthly
Interflow and Groundwater concentration of CO_2 - constant or monthly

QUALITY CONSTITUENTS ASSOCIATED WITH SEDIMENT

Washoff potency factor (each constituent) - constant or monthly
Scour potency factor (each constituent) - constant or monthly

QUALITY CONSTITUENTS ASSOCIATED WITH SURFACE RUNOFF

Rate of accumulation on surface (each constituent) - constant or monthly
Maximum storage on surface (each constituent) - constant or monthly
Rate of surface runoff removing 90% of const. per hour (each constituent) - constant

QUALITY CONSTITUENTS IN INTERFLOW AND GROUNDWATER

Concentration of const. in INTERFLOW - constant or monthly
Concentration of const. in Groundwater - constant or monthly

AGRICHEMICAL QUALITY CONSTITUENTS

Solute leaching factors (each soil layer) - constant
Soil layer depths (each of four layers) - constant
Soil bulk densities for each layer - constant
Temperature correction parameter for pesticide decay - constant
Pesticide solubility - constant
Pesticide adsorbtion - desorption parameters - constant

Execution Time

The time that the three application modules, PERLND, IMPLND and RCHRES, take to execute depends on many factors such as:

1. The time step. HSPF is designed for a variety of user-selectable time steps ranging from one minute to one day. Execution time will be approximately inversely proportional to the time step.

2. The module sections which are active. For example, with the PERLND module, a user can simulate hydrologic behavior only (sections SNOW, PWATER) or he may activate a combination of subroutines that will simulate washoff of pollutants or the behavior of agricultural chemicals. Obviously, execution time will increase in the latter case.

3. The frequency of printout. HSPF allows the user to specify a "threshold" level for printout frequency - interval, day, month, year or never. Because the production of printed summaries is quite time consuming, even for a computer, the printout threshold selected will affect execution time.

4. The number of time series being written to the Time Series Store (TSS). In HSPF, the user has the option of outputting a great variety of time series to the TSS. The number selected will affect the time of execution.

5. Other options. Each module has many options, other than those already discussed, that will affect execution time to various degrees.

6. The type of computer and operating system.

If HSPF were compared with one of its predecessor models in a test in which, as far as possible, all the factors discussed above were the same in both cases, HSPF would probably require slightly longer execution times. However, this disadvantage might be offset by choosing a larger time step than the previous model permitted.

Two sample execution times on an HP3000 Series II system are:

1. PERLND module, with only the water budget (PWATER) section active. Monthly printout, 15 minute timestep, 1 time series output to disk. 6 CPU minutes/landsegment/ simulated year.

2. RCHRES module, with only the flow routing section (HYDR) active (no quality constituents). No printout, no auxiliary output and no output to disk. 1 hour timestep. 1 outflow 1.2 CPU minutes/reach/simulated year.

Execution on an IBM 370/168 with OS operating system would be 20 to 30 times faster than the above.

Installation and Use

HSPF is available from the EPA's Athens Environmental Lab. The program is on magnetic tapes compatible with IBM 370 (OS) and HP3000 machines. Information on the cost and procedures for acquiring the program from the EPA will be provided by the EPA Environmental Research Laboratory in Athens, Georgia (Technology Development and Applications Branch. Phone: 404/546-3476). Hydrocomp, Inc. also offers the service of installing the

program on a user's IBM 370 or HP3000 computer system at a moderate cost. Adaptation and installation of the program for other computer systems is not a trivial matter. Thus, the effort and cost of such an installation may be substantial, depending upon the nature of the computer system.

One week training courses on the theory and usage of HSPF are being offered by the EPA and Hydrocomp at a standard workshop fee. Hydrocomp also offers private workshops tailored for specific users.

General maintainence and user support of the program is currently available from Hydrocomp under a short-term contract with the EPA. The EPA anticipates that this general maintenance of HSPF will continue for several more years under future contracts.

SECTION 3
HSPF CAPABILITIES AND INNOVATIVE FEATURES

HSPF DESIGN CONCEPTS AND CAPABILITIES

This section gives an overview of the processes modeled and functions performed by various modules of HSPF. First, however, we would like to discuss some of the design principles that motivated and guided the development of the program and the basic concepts used by HSPF in representing the real world. Understanding these principles and concepts is helpful if one is to grasp how HSPF works.

Design Principles

The use of models that simulate continuously the quantity and quality processes occurring in the hydrologic cycle is increasing rapidly. Recently there has been a proliferation in the variety of models and in the range of processes they simulate. This has been a mixed blessing to a user. To get the benefits of simulation, he has to select a model from a bewildering array and then spend much effort amassing and manipulating the huge quantities of data that the model requires. If he wishes to couple two or more subprocess models to simulate a complete process, he often encounters further difficulties. The underlying assumptions and/or structures of the subprocess models may make them somewhat incompatible. More frequently, the data structures are so different that coupling requires extensive data conversion work.

One reason for these problems is that the boom in modeling work has not included enough work on the development of good model structures. That is, very few software packages for water resource modeling are built on a

systematic framework in which a variety of process modules can fit.

HSPF attempts to overcome these problems as far as possible. HSPF consists of a set of modules arranged in a hierarchical structure that permit the continuous simulation of a comprehensive range of hydrologic and water quality processes. Experience with sophisticated models indicates that much of the human effort is associated with data management. This fact, often overlooked by model builders, means that a successful comprehensive model must include a sound data management component. Otherwise, the user may become so entangled in data manipulation that his progress on the simulation work itself is drastically retarded. Consequently, the HSPF software is planned around a time series management system operating on direct access principles. The simulation modules draw input from a Time Series Store and are capable of writing output to it. Because these transfers require very few instructions from the user, the problems referred to above are minimized.

The HSPF system is designed so that the various simulation and utility modules can be invoked conveniently, either individually or in tandem. A top down approach emphasizing structured design has been followed. First, the overall framework and the Time Series Management System were designed. Then, work progressed down the structure from the highest, most general level to the lowest, most detailed one. Every level was planned before the code was written. Uniform data structures, logic figures, and programming conventions were used throughout. Modules were separated according to function so that, as much as possible, they contained only those activities that are unique to them. Structured design has made the system relatively easy to extend, so that users can add their own modules with relatively little disruption of the existing code.

HSPF was developed under the following specifications.

- It must manage and perform deterministic simulation of a variety of aquatic processes which occur on and under land surfaces and in channels and reservoirs.

- It must readily accommodate alternate or additional simulation modules.

- It must permit easy operation of several modules in series, and thus be capable of feeding output from any operation to subsequent operations.

- It must be in ANSI Fortran with minor specified extensions.

- It must have a totally new design. Existing modules from its predecessor models (HSP,ARM, and NPS) should not merely be translated, but should be fitted into a new framework.

- It must be designed from the top down, using some of the new improved programming techniques such as Structured Design and Structured Programming.

- Duplication of blocks of code that perform similar or identical functions should be avoided.

- The user's control input must have a logically consistent structure throughout the package.

- Uniform standards and practices must be followed throughout the design, development and documentation of the system.

- It must have a conveniently operated disk-based Time Series Store built on the principle of direct access.

- The design must be geared to implementation on larger models of the current generation of "minicomputers." It must be compatible with Operating Systems that share machine core space using either the virtual memory approach or a conventional overlay technique.

Such specifications have led to the development of a model that is not only comprehensive but, once it is learned, will be relatively easy to use.

HSPF VIEW OF WORLD

HSPF represents the continuous spatial variations observed in the physical world (a watershed) by one or more elements of finite size made up of nodes and zones. A node corresponds to a point in space. A zone corresponds to a finite portion of the physical world. For example, a node on a stream represents a defined point along the stream and we can speak meaningfully about the flowrate in the stream at that point. Thus, the portion of the stream between two distinct points on the stream is a zone. The volume of water in a defined portion of the stream corresponds to a zone. This portion of the stream is also a single zone element. In this case the element has two nodes. A sequence of elements of this type, called channel reach elements, can represent a complex stream network.

No fixed rules govern the grouping of zones and nodes to form elements. The model builder must decide what grouping is reasonable and meaningful, based on his view of the physical processes being simulated. In general, it is convenient to define elements so that a large portion of the physical world

can be represented by a collection of conceptually identical elements. In this way, a single parameter structure can be defined that applies to every element in the group. For example, the channel reach elements discussed above all have a length associated with them. They also may have a description of the shape of the channel at each node. These are all parameters for the particular element. Each element will have potentially different values for the parameters but each channel reach element has the same number and type of parameters.

The grouping of zones and nodes is influenced by the storage and movement of material in the physical world. At any given instant of time the zones of an element will contain a given quantity of material and will also be subject to inflows and outflows (fluxes) of material at given rates. Certain nodal values, such as depth of flow in a stream, may also exist at the given instant of time. All the values needed at an instant of time to define behavior of the physical processes taking place in the element are collectively called the "state" of the system. The details of the state description for a given element and physical process depend on the characteristics of both the element and the physical process.

HSPF not only observes spatial variation in the physical world but also temporal variation. Streamflow at a node on the stream is not constant, but varies with time. The volume of water in the channel reach also varies with time. These variations are essentially continuous in nature but numerical simulation models, such as HSPF, must represent these variations as a sequence of values given at discrete points in time or as average values for discrete intervals in time. Such series of values ordered in time are called time series. The basic "element" for temporal varitions is called the time step. The time series may be represented as a sequence of average values associated with the time steps or as a series of instantaneous values associated with the time points delimiting the time steps. The average values are analogous to the zones for the spatial element and the

instantaneous values are analogous to the nodes for a spatial element. Similarly, it makes no sense to speak about an average value at a given time point because average values instrinsically depend on a finite time interval. Time series consisting of instantaneous values at discrete time points are called point-value time series. Time series consisting of average values over each time interval are called mean-value time series. Examples of a mean-value time series are the daily streamflow series reported by the United States Geological Survey in their annual reports. Examples of a point valued time series are the three-hourly values of dew point temperature and air temperature reported by the Environmental Data Service for selected stations in the United States.

The behavior of the prototype watershed is represented by physical processes occurring in the elements and by the transfer of time series among the elements. The simulation of large prototypes is made convenient by designing a single "application module" for a given element type or element group, and applying it repetitively to all similar members in the system. For example, we use the RCHRES module of HSPF to simulate the hydraulic behavior of all the reach elements in a watershed. This approach is most efficient computationally if one element or group of elements, called a "processing unit" (PU), is simulated for an extended period of time before other processing units are simulated. To permit this, we must be able to define a processing sequence such that all information required by any PU comes from sources external to the physical system or from PU's already simulated. This can only happen if the PU's and their connecting fluxes form one or more networks that are "directed graphs." In a directed graph there are no bi-directional paths and no cycles. Figure 6 shows some directed and non-directed graphs.

The requirement that PU's form directed graphs provides the rule for grouping elements into PU's. Any elements interacting with each other via loops or bi-directional fluxes must be grouped into a single PU because none

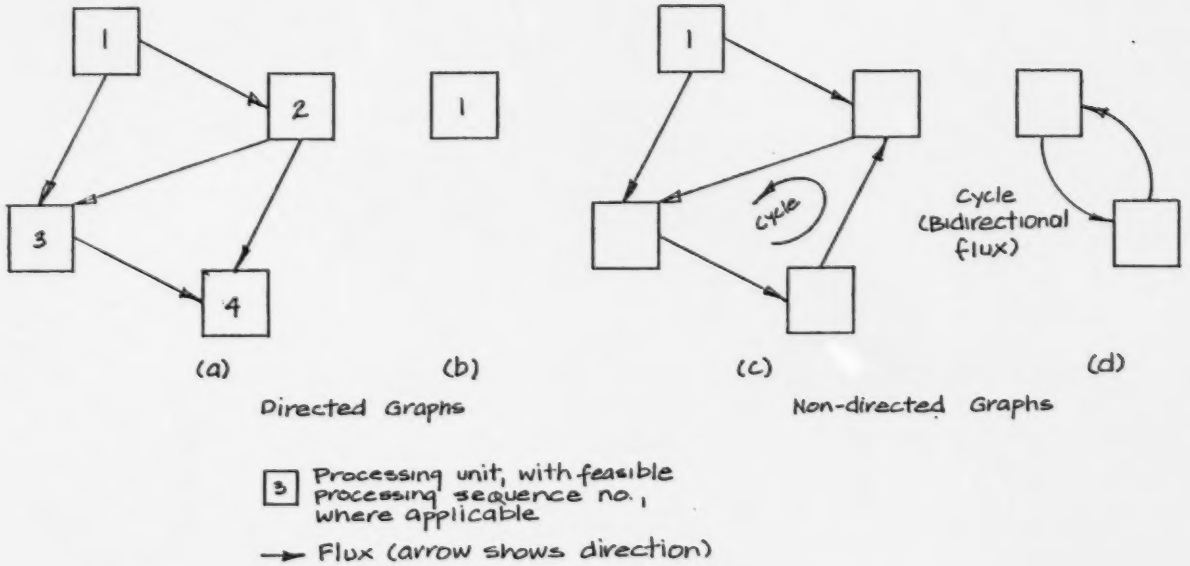

FIGURE 6 Examples of Directed and Non-Directed Graphs

of them can be simulated apart from the others. Therefore, both single and multi-element processing units are possible. A multi-element PU is also called a "feedback" region. Finally, the collection of PU's which are simulated in a given run of the programming system is called a network.

The processes that occur within a PU are represented mathematically in what is called an application model. The corresponding computer code is called an application module or simulation module.

CONTINUOUS SIMULATION

The view of the world not only includes the manner in which the physical world is represented but also the manner in which the physical processes are simulated. Two approaches are possible. The first approach, and also the traditional approach, considers only design events or critical events and therefore focuses attention on these events. Non-critical events are not examined because by definition they are not going to affect the results. The second approach considers the continuum of events and attempts to examine the probabilistic behavior of the system from the analysis of this continuum of events. Both approaches are useful and the approaches are not mutually exclusive. HSPF's design was motivated primarily by the second approach but it may be used to examine isolated or design events also.

The second approach in which a continuum of events are simulated results in a greatly increased requirement for both input and output data. HSPF, therefore, includes extensive capabilities for input, output and manipulation of time series information. These capabilities assist the user greatly in not only carrying out the simulations but also in organizing the many parts of a major modelling project. The HSPF system also contains the facility for adding utility modules (described later) to expand the

capabilities of the system as the project needs require.

CURRENT MODULES

HSPF currently contains three application modules and five utility modules. Each of these modules is briefly discussed below.

Simulate a Pervious Land Segment (module PERLND)

A land segment is a subdivision of the land area making up the drainage area of a watershed. It is represented as an element without nodes but with a number of storage zones for water and dissolved constituents. The boundaries of the segment are established according to the user's needs, but generally, a segment is defined as an area with homogenous hydrologic and climatic characteristics. For modeling purposes water, sediment, and water quality constituents leaving the segment move laterally to a downslope segment or to a stream reach or a reservoir. A segment of land that has the capacity to allow enough infiltration to influence the response of the segment is considered to be a pervious land segment. In HSPF, PERLND is the module that simulates the water quality and quantity processes that occur on a pervious land segment.

PERLND models the movement of water along three paths: overland flow, interflow and groundwater flow. Each of these three paths experiences differences in time delay and differences in interactions between water and its various dissolved constituents. A variety of storage zones are used to represent the storage processes that occur on the land surface and in the soil horizons. Snow accumulation and melt are also included in the PERLND module so that the complete range of physical processes affecting the generation of water and associated water quality constituents can be

approximated.

Figures 7, 8. and 9 depict the major physical processes simulated by PERLND. Figure 7 shows the major sources of snow and ice melt--solar radiation, long wave radiation, conduction- convection, ground melt and rainmelt. The SNOW section must also determine the form of the precipitation because precipitation records do not distinguish between liquid and solid forms of precipitation. The spatial coverage of snowpack must also be estimated because measurements are not available and this factor has a strong influence on the response of streamflow to melt. Figure 8 shows the major components of the hydrologic cycle (water budget) for a pervious land segment. PWATER uses a time series input of precipitation, or snowmelt if snow is considered, to represent the water coming into the land segment. Lateral inflows may also occur from adjacent segments as shown in the figure. Surface runoff (overland flow), interflow, and ground water flow are then the flow paths to the stream. Evaporation from land and vegetation surfaces and transpiration from vegetation (collectively referred to as evapotranspiration) make up the other major flux of water that must be modelled by the PWATER section of PERLND. Figure 9 shows the significant erosion processes involved in simulating sediment production and removal from the land surface. Rainfall splash and man-made influences are the principal sources of detatched sediment that may be transported by overland flow. Scour in rills and gullies also contributes to the production of sediment. Wind blown sources may also be an important source of fine material available for removal during the next significant runoff event. Vegative cover provides protection against erosion by both reducing the impact of rainfall and also impeding the transport of sediment by overland flow.

The following sections and capabilities exist in the PERLND module.

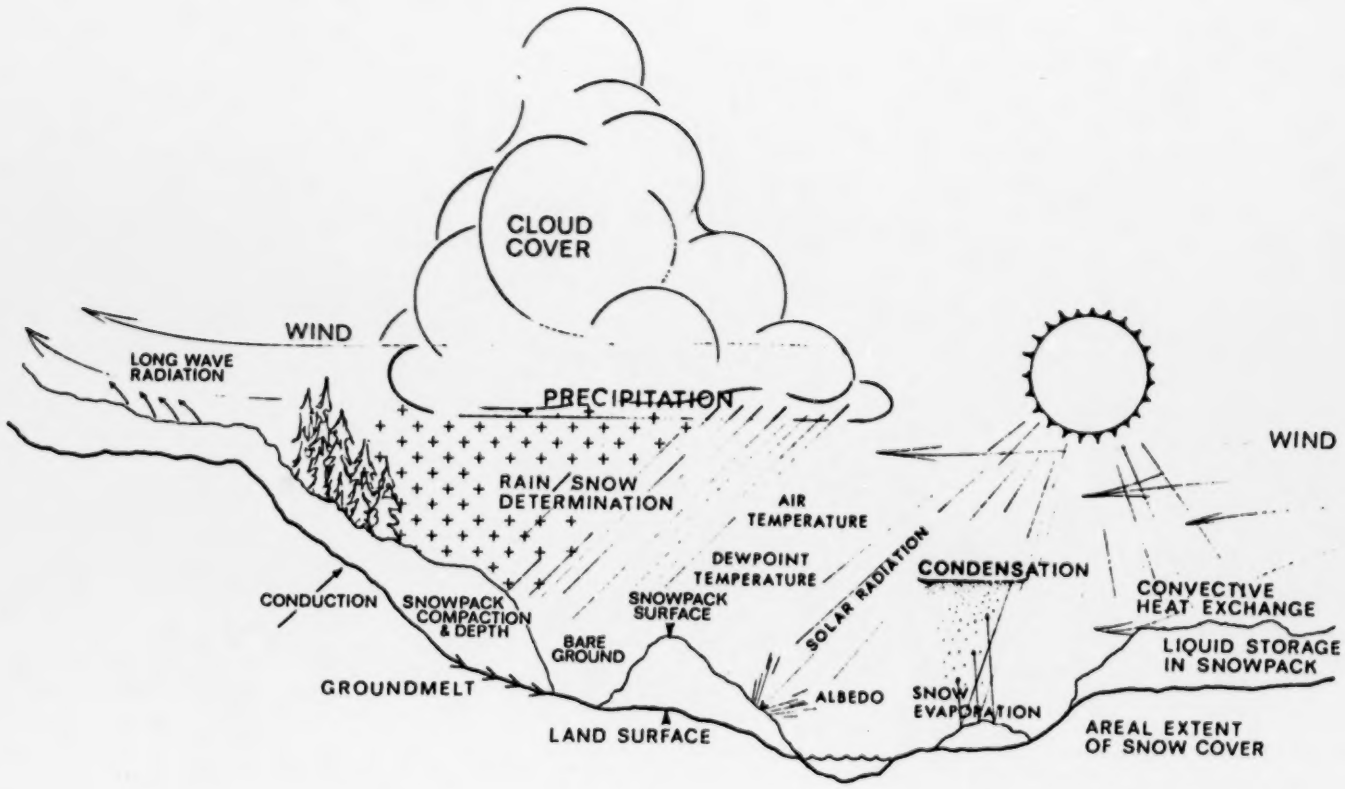

Figure 7 Snow accumulation and melt processes

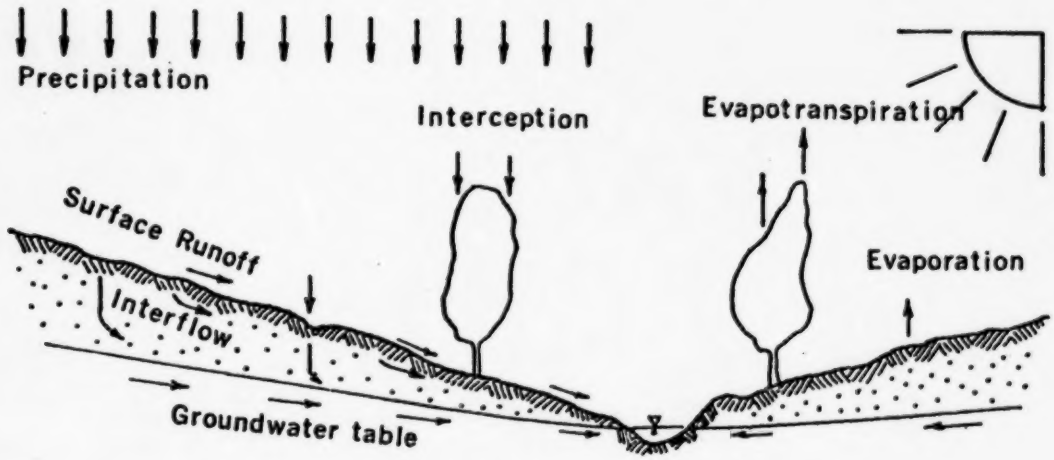

Figure 8 Hydrologic cycle

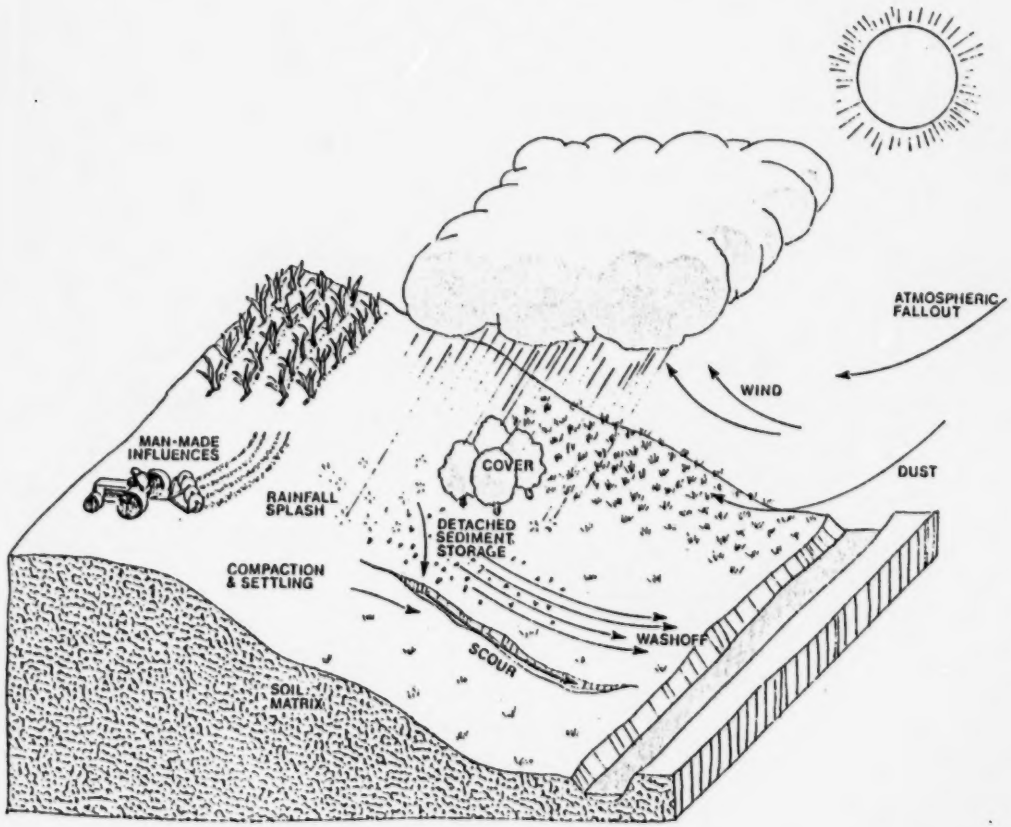

Figure 9 Erosion processes

Section	Capability
ATEMP	Correct air temperature for elevation difference.
SNOW	Simulate accumulation and melting of snow and ice.
PWATER	Simulate water budget for a pervious land segment.
SEDMNT	Simulate sediment production and removal.
PSTEMP	Estimate soil temperature.
PWTGAS	Estimate water temperature and dissolved gas concentrations.
PQUAL	Simulate quality constituents using simple relationships with sediment and water yield.
MSTLAY	Estimate moisture content of soil layers and fractional fluxes of solutes (required for following sections).
PEST	Simulate pesticide behavior in detail.
NITR	Simulate nitrogen behavior in detail.
PHOS	Simulate phosphorous behavior in detail.
TRACER	Simulate movement of a tracer.

Only those sections of PERLND needed for a given application are invoked by HSPF. Some sections are only required for simulation of particular processes and if these processes are not present, HSPF does not execute the corresponding section. In general, the sections in the list may require information generated by sections above them in the list but never require information generated sections below them in the list. Thus the application modules have been carefully designed with the flow of time series information being a major consideration in the sectioning of the modules.

Simulate an Impervious Land Segment (module IMPLND)

In an impervious land segment, little or no infiltration occurs. Some land processes, however, do occur and HSPF uses IMPLND to simulate these processes. Snow may accumulate and melt, and water may be stored or may evaporate. Various water quality constituents accumulate and are removed. Water, solids, and various pollutants flow from the segment by moving laterally to a downslope segment or to a stream reach or reservoir.

Figure 10 shows the major processes simulated by the IMPLND module. Precipitation, overland flow runoff and evaporation are the major processes affecting water. Infiltration does not occur on the impervious area so that subsurface flows (interflow and groundwater flow) are absent. Various forms of constituent sources are shown: surface oil, particles deposited from the atmosphere, vegetable residue, etc. Residues from automobile tires and brake linings also contribute to the sources of constituents transported by overland flow on an impervious segment.

The following sections and capabilities exist in the IMPLND module.

Section	Capability
IWATER	Simulate the water budget for an impervious land segment.
SOLIDS	Simulate accumulation and removal of solids.
IWTGAS	Estimate water temperature and dissolved gas concentrations.
IQUAL	Simulate washoff of quality constituents using simple relationships with solids and water yield.

IMPLND also uses some sections in the PERLND module because they are unaffected by the nature of the surface. For example, SNOW and ATEMP are

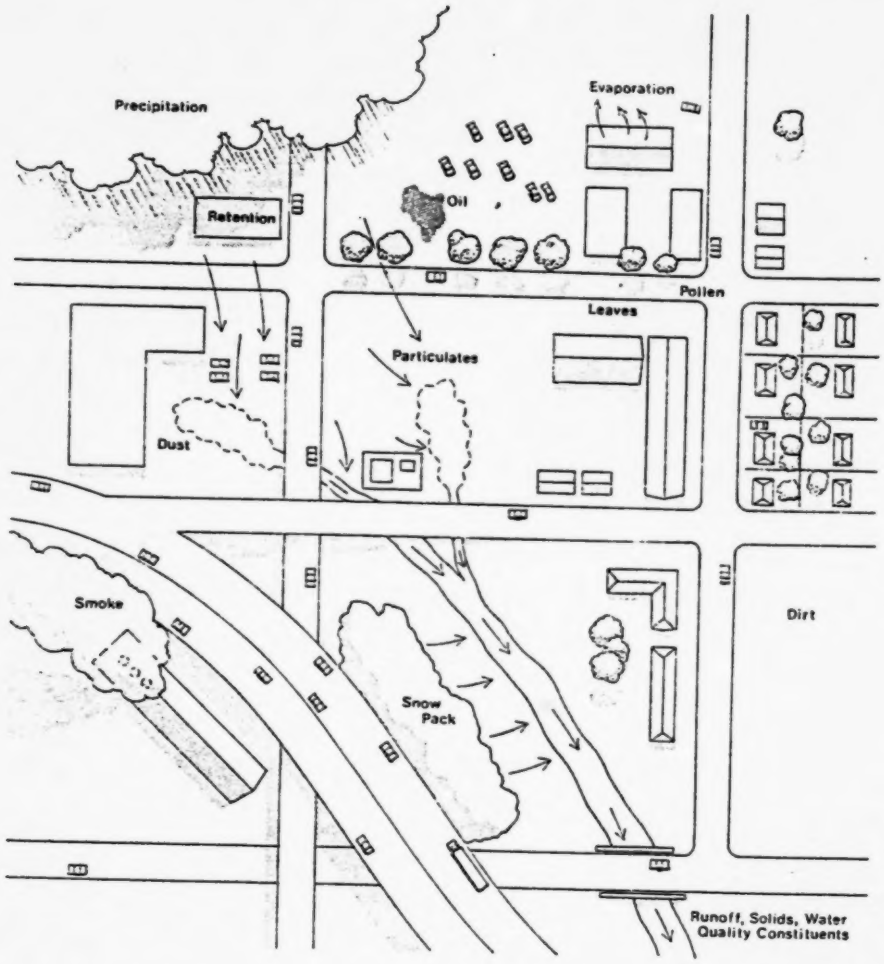

Figure 10 Impervious land segment processes

used in both IMPLND and PERLND.

Simulate a Stream Reach or a Mixed Reservoir (module RCHRES)

This module simulates the processes that occur in a single reach of an open channel or a completely mixed lake. In keeping with the assumption of complete mixing, the element consists of a single zone situated between two nodes at the extremities of the element.

Flow through the element is assumed to be unidirectional. All inflows to the element are summed and enter the element without distinction as to location of entry. The outflow from the element may be distributed across several targets by the user to properly represent normal outflow, diversions and multiple gates on a lake or reservoir. Evaporation, precipitation, solar radiation and other heat exchange fluxes take place on the surface area of the water in the element.

Figure 11 shows a schematic diagram of the flows of water and constituents in a stream reach. Surface and subsurface diffuse flows contribute both water and dissolved constituents. These non-point sources have become increasingly important in water quality studies of both urban and rural watersheds. Inflows from upstream reaches and outflows to downstream portions of the network usually represent the major flow path. Diversions from the stream to one or more distinct destinations may, however, prove to be significant. RCHRES is able to model both predetermined diversions and diversions as a function of stream stage. The air-surface and the sediment-water interchange are also important in determining the behavior of the water quality constituents in the stream. Water temperature is significantly influenced by the air-surface interchange through evaporation, solar radiation and other heat transfer processes. The sediment-water interchange affects both the nutrient and oxygen balance of the water in the

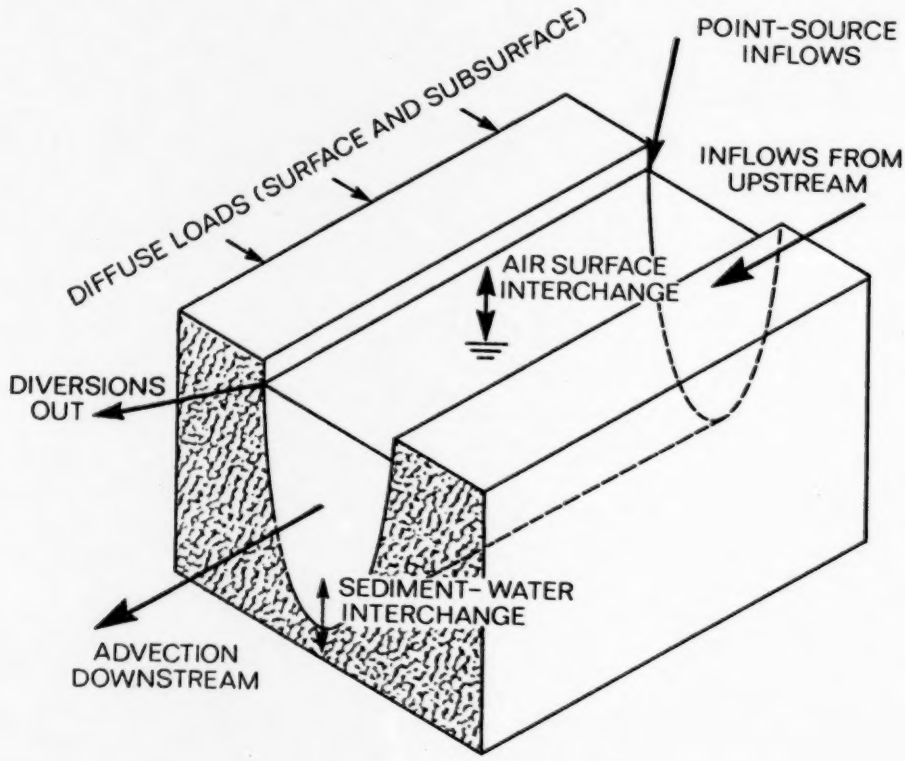

Figure 11 Flows in and out of a reach

element.

The following sections and capabilities exist in the RHCRES module.

Section	Capability
HYDR	Simulate hydraulic behavior
CONS	Simulate conservative constituents
ADCALC	Prepare to simulate advection
HTRCH	Simulate heat exchange and water temperature
SED	Simulate inorganic sediment
FSTORD	Simulate first order decay constituents
OXRX	Simulate primary dissolved oxygen and biochemical oxygen demand balances
NUTRX	Simulate primary inorganic nitrogen and phosphorous balances
PLANK	Simulate plankton populations and associated reactions
PHCARB	Simulate pH, carbon dioxide, total inorganic carbon, and alkalinity

Only those sections of RCHRES needed for a given application are invoked. Some sections are only required for simulation of particular processes and if these processes are not present HSPF does not execute the corresponding section. In general, the sections in the list may require information generated by sections above them in the list but never require information generated by sections below them in the list.

Utility Modules

The following paragraphs give brief descriptions of the five utility modules currently available in the HSPF system.

Copy Time Series (Utility module COPY). This utility module is used to copy one or more time series from a user specified source to a user specified target. The source/target may be either the Time Series Store or a sequential file on tape or card deck. A typical use of the COPY module is the transfer of data from card images to the Time Series Store. The time interval of the time series may be changed as it is stored in the TSS. The change of time interval as well as other changes in the form of the time series are under the control of the user through the facilities provided in the module TSPUT.

Prepare Time Series For Display on a Plotter (Utility module PLTGEN). This utility module prepares one or more time series for simultaneous display on a plotter. The user specifies the sources of the time series and PLTGEN creates a specially formated sequential file for later access by a stand alone plot program.

Display a Time Series in Tabular Form (Utility Module DISPLY). This utility module takes a time series, either from the TSS or directly from the operation that computes it, and summarizes the data in a neatly formated table. The interval of the data displayed in the table can be any multiple of the timestep of the time series, up to a day. Five options for the aggregation of the basic data are available--SUM, AVER, MAX, MIN, LAST. Thus, the table can show the sum, average, maximum, minimum or last value in each display interval, day, month and year.

Perform Duration Analysis on Time Series (Utility Module DURANL). This Module performs a duration and excursion analysis on a time series and also computes some elementary statistics like the mean and standard deviation. The simplest application is calculation of (flow) duration data. The user selects a set of up to 10 flow rates and the module output is the frequency with which each rate is exceeded. However, the module may also be operated

in a more advanced mode to compute the frequency with which a time series exceeds the specified level for a specified time. Thus, it can answer questions like: How often does the DO concentration stay below 4 mg/L for 2 consecutive days? This module also permits the user to specify an "analysis season" so that, for example, only data in March through September are included in the analysis.

Perform Transgeneration on Time Series (Utility Module GENER). This module permits a user to transform a time series (A) to produce a new time series (C). The available options are:

1. C = Abs (A)
2. C = SQRT (A)
3. C = Trunc (A)
4. C = Ceiling (A)
5. C = Floor (A)
6. C = $\log_e$ (A)
7. C = $\log_{10}$ (A)
8. C = $k_o+k_1A+k_2A^2+k_3A^3.....k_{10}A^{10}$

The module can also combine two input time series (A and B) to produce a new time series (C):

9. C = A+B
10. C = A-B
11. C = A*B
12. C = A/B
13. C = Max (A,B)
14. C = Min (A,B)

This module is useful when one needs to compute the outflow of a constituent, in load units, from the flow rate and concentration, or vice versa (options 11 and 12).

INNOVATIVE FEATURES

The HSPF system contains several features that are innovative in that they are not often found in programs developed in the broad field of water resources. Many of these features or techniques have been known or used in other fields. The first set of features discussed are those relating to the design of the software. Techniques developed in computer science over the last several years have been applied to the design of HSPF to improve the overall usefulness of the system. The second topic is the processing of the Users Control Input. This input is the communication medium between the HSPF program and the user. This interface has generally not been designed at the same technical level as the solution algorithms in most engineering computer programs. The HSPF system, however, has a carefully designed and consistent approach to this important part of any major program. The following section highlights some of the significant features that increase user flexibility and therefore, power in applying HSPF to problems in water resources. The last section outlines the general characteristics of the time series storage system, which is an integral part of HSPF.

Design of Software

Several techniques referred to collectively as Structured Programming Technology were used in the design and implementation of the HSPF software. These techniques included structured design, top down programming, and structured programming. The structured design involved the creation, before any code was written, of a structure chart. Figure 12 shows an example structure chart for a small part of HSPF. The structure chart defines the hierarchy of the program units and requires that each unit have a clear one-phrase description that properly summarizes it and all subordinate units. Time and effort spent at this level of the program design paid dividends in clarifying relationships among different portions of the program so that the flow of information and the subdivision of computation followed a consistent pattern. The final structure chart defines the relationships among the approximately 500 subroutines making up HSPF.

Top down programming was also used extensively to ensure consistency in details in the program units. Basically, top down programming requires that the high level program units on the structure chart be developed and partially tested before all the subordinate program units are developed. This approach coupled with structured design minimized redundant computer code and also moved code to the lowest possible level in the program unit hierarchy. As a result, attention could be focused on the necessary details at the current level and logical errors in the design of the program unit were minimized. This approach to design of a large program like HSPF results in many medium to small subroutines, each subroutine having a clearly defined purpose. This result is in direct contrast to many other large scale programs that often fail to have a clear overall design.

Structured programming was used in the detailed design and coding of the subroutines. A psuedo-code was designed to minimize the effect of the often frustrating features of the FORTRAN language. A psuedo-code is a

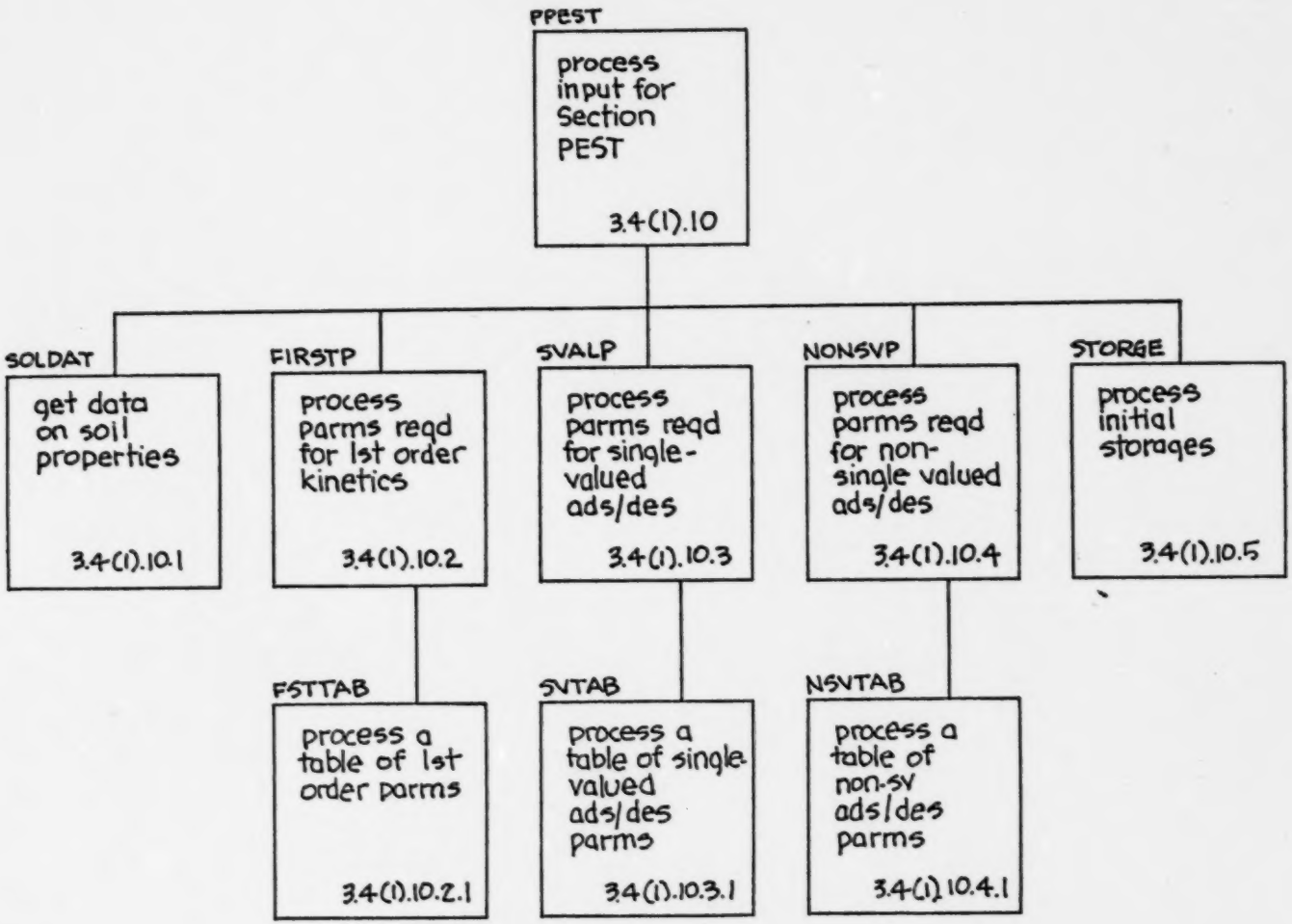

Figure 12 Example Structure Chart

programming language with simplified syntax and structure designed to conveniently document or communicate the essential concepts of the program. As such, many details normally required by a proper computer language are eliminated at the conception and design stage. These details are then added only when the psuedo-code is finally implemented in FORTRAN. The primary reason for this approach is that FORTRAN, being the first high-level programming language developed, does not contain many of the explicit language features now found to lead to improved program design. These features were included in the psuedo-code. Standard FORTRAN coding was designed for each feature in the psuedo-code. Figure 13 gives a brief example of psuedo-code and the corresponding FORTRAN. The lack of statement labels and the related GO TO statements makes the psuedo-code easier to follow and makes the hierarchy of the program statements more evident than does the FORTRAN code. Note that indentation of the FORTRAN code is used to communicate the hierarchy of the statements. This one feature alone radically improves the readability of the program code. See the unindented version for comparison.

The application of these techniques has advantages not only for the developers of the software but also the users of the software. First, the structure charts, the well defined purpose of each subroutine, and the standard format followed in the coding of each subroutine greatly ease the task of tracing errors. As experienced programmers know, no major computer program is completely tested and free of errors. Secondly, program modifications and extensions have a meaningful pattern to follow so that introduction of errors will be reduced. Changes in detailed operation of many of the subroutines can be made without affecting other parts of the program. Extensions to the capabilities of HSPF can often be made by adding one or two additional subroutines that mimic the structure of existing subroutines. These benefits existed in the original development process and will continue to exist for any user who maintains the integrity of the overall design. Third, the design of an overlay structure, required by some

FIGURE 13

EXAMPLE OF PSEUDO CODE AND CORRESPONDING FORTRAN

```
4.2(14).1

BEGIN DURDMP (J1,J2,LGTH,FREQ,S,SQ,K,NDUR,DURAT(*))

INTEGER*2 I,J,J1,J2,NDUR,DURAT(10)
INTEGER*4 K,LGTH(22)
REAL      FREQ(10,K),S(10,K),SQ(10,K)

  J= J1
  WHILEDO J <= J2
    I= 1
    WHILEDO DURAT(I)< LGTH(J) and I <= NDUR
      FREQ(I,J)= FREQ(I,J)+ 1
      S(I,J)= S(I,J)+ LGTH(J)
      SQ(I,J)= SQ(I,J)+ LGTH(J)*LGTH(J)
      I= I+ 1
    ENDDO

    LGTH(J)= 0
    J= J+ 1
  ENDDO

END DURDMP
```

Corresponding Fortran:

```
C     4.2(14).1
C
      SUBROUTINE DURDMP (J1,J2,LGTH,FREQ,S,SQ,K,NDUR,DURAT)
C
C     + + DUMMY ARGUMENTS + +
      INTEGER*2 J1,J2,NDUR,DURAT(10)
      INTEGER*4 K,LGTH(22)
      REAL      FREQ(10,K),S(10,K),SQ(10,K)
C
C     + + LOCAL VARIABLES + +
      INTEGER*2 I,J
C
        J= J1
   10   IF (J.GT.J2) GO TO 40
          I= 1
   20     IF ((DURAT(I).GT.LGTH(J)).OR.(I.GT.NDUR)) GO TO 30
            FREQ(I,J)= FREQ(I,J)+ 1
            S(I,J)= S(I,J)+ LGTH(J)
            SQ(I,J)= SQ(I,J)+ LGTH(J)*LGTH(J)
            I= I+ 1
            GO TO 20
   30     CONTINUE
```

FIGURE 13 (Continued)

```
            LGTH(J)= 0
            J= J+ 1
            GO TO 10
   40    CONTINUE
C
      RETURN
      END
```

Fortran with no indentation of statements:

```
C     4.2(14).1
C
      SUBROUTINE DURDMP (J1,J2,LGTH,FREQ,S,SQ,K,NDUR,DURAT)
C
C     + + DUMMY ARGUMENTS + +
      INTEGER*2 J1,J2,NDUR,DURAT(10)
      INTEGER*4 K,LGTH(22)
      REAL      FREQ(10,K),S(10,K),SQ(10,K)
C
C     + + LOCAL VARIABLES + +
      INTEGER*2 I,J
C
      J= J1
   10 IF (J.GT.J2) GO TO 40
      I= 1
   20 IF ((DURAT(I).GT.LGTH(J)).OR.(I.GT.NDUR)) GO TO 30
      FREQ(I,J)= FREQ(I,J)+ 1
      S(I,J)= S(I,J)+ LGTH(J)
      SQ(I,J)= SQ(I,J)+ LGTH(J)*LGTH(J)
      I= I+ 1
      GO TO 20
   30 CONTINUE
      LGTH(J)= 0
      J= J+ 1
      GO TO 10
   40 CONTINUE
C
      RETURN
      END
```

computers for a program of this size, is simplified because the structure charts clearly outline the relationships among the many subroutines in HSPF. Fourth, many of the application modules discussed in Section 7 were broken into sections on the basis of structured design concepts. This sectioning not only yields benefits in visualizing the operation of the module but also yields cost savings in operation. The output from a given section can be saved on the time series store and recalled at a later time for repeated use by one or more later sections. Last of all, every major program must be updated and maintained. Changes to operating systems are inevitable and some of these changes will affect the details of operation of HSPF. New project requirements as well as corrections to the existing program code will result in continued needs for changing the program code. The effort expended in improving the ease of changing and maintaining HSPF at the design level will therefore yield benefits for users of the program over the life of HSPF.

User's Control Input Processing

The User's Control Input (UCI) is the communication medium between the program and the user. This medium is, therefore, very important and a consistent design was developed in order to structure the User's Contol Input to increase user convenience and to permit comprehensive error detection and reporting. Some innovative features of the UCI in HSPF are discussed below.

As with most models, the UCI is supplied as card images. That is, each record has space for 80 characters, like a punched card. However, the data are often physically resident on a magnetic disc instead of punched cards. The UCI is block structured; that is, the cards are arranged in groups. Each of which starts with a heading card and ends with a delimiter card (end heading). The blocks are arranged in a hierarchical format, with major

blocks containing subordinate blocks. The initial heading is RUN, and the final delimiter is END RUN. Examples of the UCI are given in the Appendix to this Executive Summary. The reader should examine them while reading the material that follows as they help to illustrate some of the comments.

In the HSPF system, any card with three or more consecutive asterisks or any blank card is ignored. This enables the user to set out his input neatly and to insert comments to remind him what the numbers represent. In the global block, the user supplies global information such as the start and end dates.

A convenient feature of increasing importance is the ability to specify units for the program inputs and outputs. HSPF has two sets of standard units: English and metric. The user may select the system to be used for time series input, time series output, output to the printer and User's Control Input. Each of these four groups must have the same unit system for its various components. For example, all time series inputs must use the same unit system but the time series outputs may use the other unit system. Output to the printer can also be requested in dual units. HSPF automatically converts the unit systems to a common base as the operations requested by the user are done.

A valuable convenience feature is illustrated by the starting and ending time specifications in the GLOBAL block group of statements (see examples in Appendix). The user may specify starting and ending times to the nearest minute but default values will be supplied by the program for all but the year. The starting time defaults are taken as the starting time of the last item given by the user in the starting date/time specification. For example, if year and month are given for a starting time, then the simulation begins at the start of the month give. On the other hand, the ending time defaults are taken at the ending time of the last item given in the date/time specification. For example, if year and month are given, then the

simulation ends at the end of the month are given. These two conventions, the former called the starting time convention and the latter called the ending time convention, have been defined in this manner because users in the past have found these conventions to be meaningful. Attempts to use either the ending time or the starting time convention throughout have met with misconceptions and unneeded errors. Note that the starting time and ending time conventions apply through the minute field so that there is no ambiguity about the precise instant of starting or ending the simulation.

In the OPN SEQUENCE Block, the user specifies the operations involved in the run and the sequence in which they are to be performed. Thus, if a network of reaches is being simulated, they must be mentioned in the OPN SEQUENCE Block in an upstream to downstream sequence, as no reach can be simulated ahead of one which is tributary to it.

"Operation-type" Blocks supply the data that are domestic to all operations in the run of a given operation-type (eg., the PERLND block supplies data applicable to all the Pervious Land- Segments). These blocks contain several sub-blocks called "tables."

Default values are available wherever they are meaningful. Some information in the User's Control Input, of course, does not have meaningful default values and therefore none are supplied. Other information has meaningful default values but they should be used with care. This is especially true of the parameters for the application modules. Default values have been given for completeness but the user should supply estimates instead of using them. HSPF will report an error if the user omits one or more values which do not have default values.

Another convenient feature is the checking of valid ranges for all inputs having a meaningful range. These ranges have been set during the development of HSPF but they can be changed by the user without changing the

program. Thus the occasional unforeseen extreme condition on the range of one or more parameters does not require modifying the computer program. This validity checking of parameters screens for gross errors in the User's Control Input and therefore limits the probability of expensive catastrophic errors when submitting a costly computer run.

A final convenient feature of note is the subdivision of the input into logical blocks and tables. Parameters have been grouped on the basis of their function and their relationship to other parts of the input. Such groupings not only benefit the user in preparing the input but also help to standardize the program code that does the parameter checking. The heading for each table specifies the table-type. This is followed by one or more cards containing the "body" of the table. Each of these cards starts with a "range" specification, that gives the land segment numbers or reach numbers for which the data are applicable. This feature permits the input to be more compact than otherwise. For example, if there are 100 reaches in a network, all having the same input values, it can be handled in a single line having the range specified as 1 through 100. The range specification is followed by the actual data.

All the values in some input tables will be supplied by default if the table is not given. A message informing the user of that action is given in the output from the printer. On the other hand, a table not needed for a particular series of operations, called a redundant table, does not cause an error. The table is processed and checked but not used by HSPF. This treatment of redundant input tables is very convenient should the user wish to rerun a subset of a complex run. There is then no need to create an abbreviated input sequence. Only a few tables need to be modified and the excess tables for the abbreviated run will have no effect on the results.

Error Handling

Discussion of the convenience features has raised the issue of error reporting. HSPF has defined two classes of error conditions: warnings and errors. A warning is a potential problem condition detected by HSPF that is not sufficiently severe to terminate processing. Each warning message will be repeated for a given condition until a preset maximum number of messages are output. Subsequent messages are suppressed so that the output is not cluttered with repetitive occurrences of the same message. Errors are problem conditions that will terminate processing if they occur during the operations specified by the user or will eventually prevent initiation of these operations if detected in the analysis of the User's Control Input before HSPF elects to terminate the analysis. One or more errors detected during user input stream analysis prevents initiation of the operations requested by the user.

An example of an error message is shown in Figure 14. The message is clearly set apart with a box made of asterisks so that the message can be clearly seen even though imbedded in many lines of other output. The message identification number is the line number at which the message is given in the error message file used by HSPF. This file contains all error messages as well as optional comments for all error conditions detected by HSPF. The user gets his error message documentation merely by listing this file.

As a result, no discrepancy between the error message reported by HSPF and the error message comments contained in the program documentation can exist. Each installation of HSPF will have both an error message and a warning message file that will be current with that release of HSPF. This approach to error and warning message handling not only standardized the program code but also minimized the chance for confusing discrepancies between program output and program documentation. This approach also makes updating of the messages possible without requiring program modification.

User Flexibility

An important feature of any program that analyses many differing situations is the flexibility with which it describes these situations and reports the results. Two significant features of HSPF that relate to the reporting of the results are the user control of summary printing and the manipulation of time series.

Summary Printing. The user specifies the minimum interval of summary printout; a given number of simulation time steps, day, month, year or never. HSPF then generates reports at that interval and all greater intervals. Thus, requesting printout of the physical process status at the end of each day of simulation time also yields end of month and the end of year status. Furthermore the user may specify the number of the month (1-12) that shall be considered the end of the year for printout purposes. This feature can then create end of water- year summaries for a user defined water year. The printout frequency can be specified for each module section so that detailed printout is generated for only a selected subset of all the sections invoked by the user. This allows the user to focus attention on the results from a specific section in order to more fully understand the results or to improve the current parameter set used to describe the physical process. Of course, the ultimate option of suppressing all printout exists and might be useful for certain operations. This option should, however, be used with care.

Manipulation of Time Series. The ability to access time series with a minimum of restrictions is an essential feature of HSPF. Each application or utility module contains a predefined set of time series variables that the user may request to be output to the Time Series Store (TSS) or passed on to a subsequent module. Table 5 contains the catalog for the HYDR group of the

Table 5
CATALOG OF TIME SERIES IN HYDR GROUP OF RCHRES MODULE

<---- Member ----> Name	Max subscr values 1	2	K i n d	Units (external) Engl	Metr	Description/comment
Time series computed by module section HYDR:						
VOL	1	1	*	ac.ft	Mm3	Volume of water in the RCHRES
AUX1FG must be 1 for next 5 members to be computed:						
DEP	1	1	*	ft	m	Depth at specified location
STAGE	1	1	*	ft	m	Stage (DEP+STCOR)
AVDEP	1	1	*	ft	m	Average depth (volume/surface area)
TWID	1	1	*	ft	m	Mean topwidth (surface area/length)
SAREA	1	1	*	ac	ha	Surface area
AUX2FG must be 1 for next 2 members to be computed:						
AVVEL	1	1	*	ft/s	m/s	Average velocity (RO/VOL)
AVSECT	1	1	*	ft2	m2	Cross-sectional area averaged over length of RCHRES (VOL/length)
RO	1	1	*	ft3/s	m3/s	Total rate of outflow from RCHRES
O	NEXITS	1	*	ft3/s	m3/s	Rates of outflow through individual exits
PRSUPY	1	1	-	ac.ft/ ivld	Mm3/ ivld	Volume of water contributed by precip on surface
VOLEV	1	1	-	ac.ft/ ivld	Mm3/ ivld	Volume of water lost by evap
ROVOL	1	1	-	ac.ft/ ivld	Mm3/ ivld	Total volume of outflow from RCHRES
OVOL	NEXITS	1	-	ac.ft/ ivld	Mm3/ ivld	Volume of outflow through individual exits

RCHRES module. This catalog describes the units of the data, the kind of data (point valued:*, mean valued:-), and the nature of the data. Many of these time series are not required for input to any other module but such time series are useful in understanding behavior of the physical process as simulated by the module.

The ability to transfer time series among modules is also an essential feature of HSPF. Two methods are available for this transfer. The user may elect to store the time series in the TSS for access in a later module, or a later run. This method would be useful if a copy of the time series will be needed over a period of time by one or more runs. The second method uses the internal scratch pad (INPAD) to transfer time series between modules. This method of transfer is often useful for passing time series that are not needed for later access. This method also minimizes the storage and input/output time used in accessing the TSS. Both methods may be used simultaneously for the same time series. That is, the time series may be passed between modules by using the INPAD and at the same time the user can request that a copy be placed on the TSS.

Lastly, HSPF has the ability to perform transformations on time series. These transformations are used to change the time interval or kind of the time series. For example, a point-valued time series may be converted to a mean valued time series in several ways depending on the time step ratio and user needs. One useful transformation finds the maximum value of the source time series within each of the time intervals of the target time series. Another transformation will use linear interpolation to subdivide a larger time interval into a smaller time interval. HSPF again uses default values for some transformations that the user may override as necessary.

Time Series Storage. Much of the user flexibility in manipulating time series depends on the TSS. The TSS is a large dataset (data file) on a direct access device. HSPF contains special modules that are used to

subdivide this dataset into smaller units for storage of time series. These smaller units are called time series datasets. These datasets are created, manipulated and known by HSPF only. The operating system of the computer on which HSPF is executed knows only of the TSS dataset. This approach to storing the time series was selected because many years of experience with similar systems showed a number of advantages. First, the job control language needed for HSPF is not a function of the number of time series involved in the operations performed by HSPF. Second, the storage of time series may be tailored to the needs of HSPF and is not limited by the input/output features provided by the host computer (direct disc access must be available, however.). Third, obtaining backup copies of the TSS is simplified because only the one dataset need be copied to a magnetic tape. These advantages are not, however, gained without some potential disadvantages. The first disadvantage is that sufficient space must be allocated for the TSS for all time series operations for a project or group of projects. The costs for this space may be prohibitive unless the computer facility supports dismountable storage media for its direct access devices. Nearly all computer systems have this capability but not all computer centers allow its use. The second disadvantage is that input/output efficiency is reduced because all time series data is concentrated into one dataset from the point of view of the operating system. This is a price that must be paid to reap the advantages. Our experience is that this cost is relatively small.

The format of the data in the TSS is specific to HSPF to take full advantage of the concept of having HSPF define the nature of the time series storage medium. Two features of the format affect the user and provide significant advantages in handling time series data. The first feature is the ability to store vector-valued time series. A vector valued time series is a time series for which two or more values are recorded at each time point in the series. A typical example would be the quantity and quality of a treatment plant outfall. The information would include the flow rate, the

temperature, the biochemical oxygen demand, the dissolved oxygen, etc. Each of these values could be stored as a separate independent time series in the TSS. But these time series are closely related because they all derive from the same physical source: the treatment plant outfall. They will also be used together for many of the simulation applications. Therefore, HSPF has the option to store these values in one time series data set with several members. All the members must have the same time interval but all other characteristics can differ. Each member can be referenced individually or the entire set of members can be referenced simultaneously in the Users Control Input. The logical grouping of time series provided by this feature permits the user to focus attention on the relationships among groups of time series instead of becoming enmeshed in the details of bookkeeping to maintain order among potentially hundreds of time series for a large project.

The second feature is optional suppression of redundant zero values in the time series. Some time series, such as hourly rainfall, surface runoff, and any constituents transported by surface runoff, are predominately zero. Thus, much of the space required for storage of these time series would be occupied by zero values. A special compressed storage format has been designed to greatly reduce the space required to store such time series. The compressed form of storage requires only a fraction of the space required for uncompressed storage for time series containing long sequences of zero values.

```
**********************************************************************************
*                                                                                *
* Error Message ID:   436                                                        *
*                                                                                *
* Run Interpreter                                                                *
*                                                                                *
*                                                                                *
* The following values were specified for a starting date/time but are           *
* invalid. (Were they placed in the wrong fields?):                              *
*                                                                                *
*  YEAR  MON  DAY   HR  MIN                                                      *
*  1976   13    1    0    0                                                      *
*                                                                                *
**********************************************************************************
```

Figure 14 Sample Error Message

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APPENDIX TO THE EXECUTIVE SUMMARY

Examples of HSPF Users
Control Input

1.0 USER'S CONTROL INPUT TO COPY TIME SERIES INTO THE TIME SERIES STORE

The following is a listing of the User's Control Input (UCI) which was used to input two time series into the Time Series Store (TSS).

The lines commencing with ! are job control statements (file specifications, etc.) required to run HSPF on a HP3000 computer. These vary from one type of machine to another.

The GLOBAL Block specifies the period for which data are being input (June 1974), and some other general control information.

The OPN SEQUENCE Block indicates that there are two COPY operations in the run, the first having a time step of 1 hour and the second 24 hours. Note that, if the time steps had been the same, the two time series could have been input in a single COPY operation; module COPY can handle up to 20 point-valued and 20 mean-valued time series in a single operation.

The COPY Block indicates that, for both COPY operations, a single mean-valued time series is being handled.

The EXT SOURCES Block specifies that:

1. The file with Fortran unit no. 21 contains hourly data (format HYDHR), in Metric units. Missing records are assumed to contain zeros (like NWS hourly precipitation cards). The multiplication factor field is blank, so defaults to 1.0. The time series goes to COPY operation no. 1 (time series group INPUT, member MEAN 1).

2. The file with Fortran unit no. 22 contains daily data (format HYDDAY) in Metric units. This time series goes to COPY operation no. 2.

The EXT TARGETS Block specifies that:

1. The output from COPY operation no. 1 (which came from sequential file 21) goes to dataset no. 25 in the TSS (member PRECIP 1) and is stored in Metric units. The access mode is ADD.

2. Similarly, the output from COPY operation no. 2 is to be stored in member PETDAT 1 of TSS dataset no. 26.

Note that the labels for the TSS datasets must have previously been created, and that the member id and unit system info (METR) supplied by the user must agree with the corresponding information in the label.

Module COPY is essentially a null operation. The work is done by module TSGET which inputs the time series (using info from EXT SOURCES Block) and module TSPUT which outputs it (using info from the EXT TARGETS Block). COPY

does nothing to the time series; it is there because the system requires an operating module as a link between TSGET and TSPUT.

```
!JOB JUNE1974,RCJ.P8004
!FILE FTN01=INFOFL.RCJ.P7614,OLD;ACC=IN
!FILE FTN02;REC=-84,3,F,ASCII
!FILE FTN03=ERRFL.RCJ.P7614,OLD;ACC=IN
!FILE FTN04=WARNFL.RCJ.P7614,OLD;ACC=IN
!FILE FTN05=$STDIN
!FILE FTN07;REC=-22,11,F,BINARY
!FILE FTN08;REC=1000,1,F,BINARY
!FILE FTN09;REC=300,1,F,BINARY
!FILE FTN10;REC=300,1,F,BINARY
!FILE FTN12;REC=60,6,F,BINARY
!FILE FTN15=TSSFL.RCJ.P8004,OLD
!FILE FTN21=PRECDATA,OLD
!FILE FTN22=PETDAT,OLD
!SETDUMP
!RUN HSPFPF.USLS.P7614
RUN

GLOBAL
  Inputting test data to TSS
  START       1974/06          END    1974/06
  RUN INTERP OUTPUT LEVEL    3
  RESUME     0 RUN     1
END GLOBAL

OPN SEQUENCE
      COPY          1   INDELT 01:00
      COPY          2   INDELT 24:00
END OPN SEQUENCE

COPY
  TIMESERIES
    #thru#  NPT  NMN ***
    1    2         1
  END TIMESERIES
END COPY

EXT SOURCES
<-Volume-> <Srcfmt> SsysSgap<--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name>   #          tem strg<-factor->strg <Name>   #   #        <Name> # #  ***

SEQ     21 HYDHR    METRZERO               COPY     1     INPUT  MEAN   1
SEQ     22 HYDDAY   METRZERO               COPY     2     INPUT  MEAN   1
END EXT SOURCES
```

```
EXT TARGETS
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Volume-> <Member> Tsys Tgap Amd ***
<Name>   #        <Name> # #<-factor->strg <Name>   # <Name> #  tem strg strg***
COPY     1 OUTPUT MEAN   1                TSS     25 PRECIP 1 METR      ADD
COPY     2 OUTPUT MEAN   1                TSS     26 PETDAT 1 METR      ADD
END EXT TARGETS

END RUN
!EOD
!EOJ
```

2.0 USER'S CONTROL INPUT TO SIMULATE PWATER, SEDMNT, MSTLAY AND PEST SECTIONS OF THE PERLND APPLICATION MODULE

The following is a listing of the User's Control Input (UCI) to run the PERLND Application Module, with the PWATER, SEDMNT, MSTLAY and PEST sections active. Features of the input which are common to those discussed in the previous example will not be described again.

The OPN SEQUENCE Block indicates that a single Pervious Land-segment (PLS) is being simulated.

The PERLND Block specifies the parameters and initial conditions. Table ACTIVITY indicates which module sections are active. It is possible to have any meaningful set of the sections active. Table PRINT-INFO indicates that printout will be produced every interval, because the print level flag for every section is set to 2 and PIVL = 1.

Table GEN-INFO specifies that Land-segment CRUD is to be subdivided into 3 areal source "blocks", that all inputs are in the English unit system (unit flags= 1), that printout in the English system is to go to Fortran file no. 6, and that there is not to be any printout in the Metric system.

The parameters for section PWATER appear in Tables PWAT-PARM1 through PWAT-PARM4. The initial conditions are contained in Tables PWAT-STATE1 and PWAT-BLKSTAT. Note that three of the latter are required because the land-segment is divided into three blocks.

The parameters for section SEDMNT are specified in Tables SED-PARM2 and SED-PARM3.

If the user does not supply an expected table, or if he leaves one or more fields blank in a table, HSPF supplies default values (where they exist). Thus, in this example, NSUR (in Table PWAT-PARM4), all values in Tables SED-PARM1 and SED-STOR, and all the MSTLAY parameters and initial conditions will be defaulted.

Table PEST-FLAGS indicates that only one pesticide is being simulated (NPST= 1) and that adsorption/desorption will be simulated using first-order kinetics (ADOPFG=1). Tables SOIL-DATA through PEST-DEGRAD specify pesticide

related parameters; Table PEST-FIRSTPM is repeated for each of the four soil layers that HSPF simulates (surface through groundwater). The initial storages of pesticide appear in Table-type PEST-STOR1. A table of this type is expected for every soil layer and, for the surface and upper layers, for every areal source block. Because tables of this type for the lower and groundwater layers are absent, initial storages in these layers will default to zero.

The EXT SOURCES Block indicates that all the required input time series are to come from the TSS. Note that the same time series is being used to supply the surface, upper and lower/groundwater layer temperatures. Thus, temperatures throughout the soil profile will be the same. To get a more realistic soil temperature distribution, the user could have specified separate sources for each of the temperature time series (possibly obtained from observed data). Alternatively, he could have activated section PSTEMP of this module, to compute the time series. In that case, the temperature data would automatically be passed to section PEST. And, because the data were computed, there would be no need to specify them as inputs in the EXT SOURCES Block; in fact, it would be an error to do so.

The value SAME (in the EXT SOURCES Block) means that, if the temperature data in the TSS have a larger time interval (say, day) than the simulation interval (30 mins), the disaggregated data will have the same values for an entire day. The default functional in such a case is DIV, which would cause the daily values to be divided into 48 equal 30-minute values; this is appropriate for data like potential ET but not for temperatures!

Note that there is no NETWORK or EXT TARGETS Block because there is only one operation in the run and no time series are being written to any external file.

```
!JOB PERLTEST,RCJ.P8004
!FILE FTN01=INFOFL.RCJ.P7614,OLD;ACC=IN
!FILE FTN02;REC=-84,3,F,ASCII
!FILE FTN03=ERRFL.RCJ.P7614,OLD;ACC=IN
!FILE FTN04=WARNFL.RCJ.P7614,OLD;ACC=IN
!FILE FTN05=$STDIN
!FILE FTN07;REC=-22,11,F,BINARY
!FILE FTN08;REC=1000,1,F,BINARY
!FILE FTN09;REC=300,1,F,BINARY
!FILE FTN10;REC=300,1,F,BINARY
!FILE FTN12;REC=60,6,F,BINARY
!FILE FTN15=TSSFL.RCJ.P8004,OLD
!SETDUMP
!RUN HSPFPF.USLS.P7614
RUN

GLOBAL
  Testing sections PWATER, SEDMNT, MSTLAY and PEST with FSTORD option & NBLKS=3
  START       1990/01/01 00:00  END    1990/01/01 06:00
  RUN INTERP OUTPUT LEVEL    3
  RESUME     0 RUN     1
END GLOBAL
```

```
OPN SEQUENCE
     PERLND       1   INDELT 00:30
END OPN SEQUENCE

PERLND
  ACTIVITY
    #thru# ATMP SNOW PWAT  SED PSTP PWTG PQAL MSTL PEST NITR PHOS TRAC ***
    1    5    0    0    1    1    0    0    0    1    1
  END ACTIVITY
  PRINT-INFO
    #thru#  <-------------print level FLAGS ------------------------> PIVL ***
    1    5    2    2    2    2    2    2    2    2    2    2    2    2    1
  END PRINT-INFO
  GEN-INFO
    #thru#       Name           NBLKS   Unit systems Printout files ***
    1       Land-segment CRUD       3    1    1    1    6    0
  END GEN-INFO

  TABLES FOR SECTION PWATER ***

  PWAT-PARM1
    #THRU# CSNO RTOP ***
    1    5    0    1
  END PWAT-PARM1
  PWAT-PARM2
    #THRU#*** FOREST      LZSN     INFILT      LSUR      SLSUR      KVARY      AGWRC
    1           0.5       5.0       .30       400.       .01        .00        .98
  END PWAT-PARM2
  PWAT-PARM4
    #THRU#***  CEPSC      UZSN      NSUR      INTFW       IRC      LZETP
    1                     1.5                  2.0        .50       .50
  END PWAT-PARM4
  PWAT-STATE1
    #THRU#***    CEPS      SURS        UZS       IFWS       LZS       AGWS       GWVS
    1    5                             2.0        6.0      10.0       30.0
  END PWAT-STATE1

  PWAT-BLKSTAT       Block 1
    #thru#   Surface     Upper      Iflw ***
    1    5       0.0       2.0       6.0
  END PWAT-BLKSTAT
  PWAT-BLKSTAT       Block 2
    #thru#   Surface     Upper      Iflw ***
    1    5       0.0       2.0       6.0
  END PWAT-BLKSTAT
  PWAT-BLKSTAT       Block 3
    #thru#   Surface     Upper      Iflw ***
    1    5       0.0       2.0       6.0
  END PWAT-BLKSTAT
```

```
*** Values in Table-type SED-PARM1 defaulted
SED-PARM2
  #thru#      SMPF       KRER       JRER      AFFIX      COVER       NVSI***
  1                       5.0        2.0        .01        0.5
END SED-PARM2
SED-PARM3
  #thru#      KSER       JSER       KGER       JGER ***
  1            3.0        2.0        0.0        1.0
END SED-PARM3

*** All MSTLAY parameters and initial conditions set to default values

*** Pesticide ***

PEST-FLAGS
  #thru# NPST<------ITMXPS-->-<----ADOPFG---> ***
                    1    2    3    1    2    3 ***
  1    5    1                     1
END PEST-FLAGS

SOIL-DATA
  #thru#     Depth of each layer (in)       ***
        Surface   Upper   Lower  Ground     ***
  1    5    .125     6.0    72.0    72.0
END SOIL-DATA

PEST-ID
  #thru#<--- Pesticide -----> ***
  1    5 Ant-killer #1
END PEST-ID

PEST-FIRSTPM          Surface layer
  #thru#     KDSPS      KADPS ***
  1    5       1.0        1.0
END PEST-FIRSTPM

PEST-FIRSTPM          Upper layer
  #thru#     KDSPS      KADPS ***
  1    5       1.0        1.0
END PEST-FIRSTPM

PEST-FIRSTPM          Lower layer
  #thru#     KDSPS      KADPS ***
  1    5       1.0        1.0
END PEST-FIRSTPM

PEST-FIRSTPM          Groundwater layer
  #thru#     KDSPS      KADPS ***
  1    5       1.0        1.0
END PEST-FIRSTPM
```

```
PEST-DEGRAD
  #thru#   Surface     Upper      Lower     Ground ***
  1    5      0.01       0.01       0.01       0.01
END PEST-DEGRAD

Block 1 ***
PEST-STOR1        Surface Layer
  #thru#     Cryst        Ads      Soln  (lb/ac) ***
  1    5      10.0
END PEST-STOR1

PEST-STOR1        Upper Layer
  #thru#     Cryst        Ads      Soln  (lb/ac) ***
  1    5                100.0
END PEST-STOR1

Block 2 ***
PEST-STOR1        Surface Layer
  #thru#     Cryst        Ads      Soln  (lb/ac) ***
  1    5      10.0
END PEST-STOR1

PEST-STOR1        Upper Layer
  #thru#     Cryst        Ads      Soln  (lb/ac) ***
  1    5                100.0
END PEST-STOR1

Block 3 ***
PEST-STOR1        Surface Layer
  #thru#     Cryst        Ads      Soln  (lb/ac) ***
  1    5      10.0
END PEST-STOR1

PEST-STOR1        Upper Layer
  #thru#     Cryst        Ads      Soln  (lb/ac) ***
  1    5                100.0
END PEST-STOR1

END PERLND
```

```
EXT SOURCES
<-Volume-> <Member> SsysSgap<--Mult-->Tran <-Target vols> <-Grp> <-Member-> ***
<Name>   # <Name> # tem strg<-factor->strg <Name>   #   #        <Name> # #  ***

TSS      11   PREC   ENGL                    PERLND   1     EXTNL  PREC
TSS      13 PETNUL   ENGL                    PERLND   1     EXTNL  PETINP
TSS      11   TEMP   ENGL              SAME  PERLND   1     PSTEMP SLTMP
TSS      11   TEMP   ENGL              SAME  PERLND   1     PSTEMP ULTMP
TSS      11   TEMP   ENGL              SAME  PERLND   1     PSTEMP LGTMP

END EXT SOURCES


END RUN
!EOD
!EOJ
```

3.0 USER'S CONTROL INPUT TO SIMULATE A SET OF PERVIOUS LAND-SEGMENTS, FREE-FLOWING REACHES AND A RESERVOIR

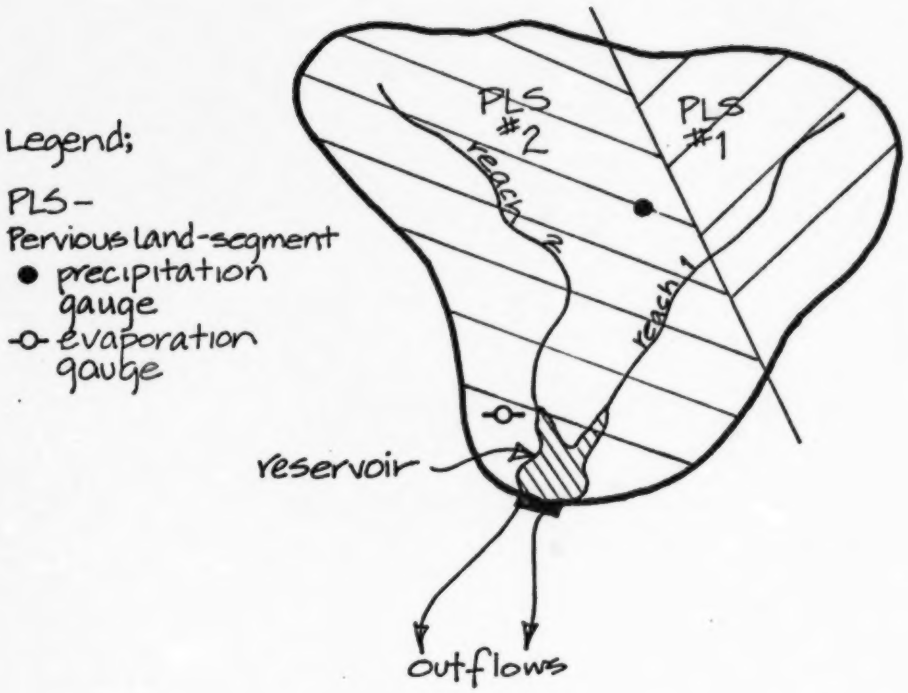
The following is a listing of the User's Control Input (UCI) to simulate two pervious land-segments (PLS 1 & 2) which feed into two free-flowing reaches (RCHRES 1 & 2) which then discharge into a reservoir (RCHRES 3). The setup is diagrammed in Figure 1.

The OPN SEQUENCE Block specifies that the two PERLND operations, three RCHRES operations, and a PLTGEN operation, are all in the same INGRP. Thus, they have the same internal time step (30 min) and share the same internal scratch pad. All time series transfers between these operations can therefore take place internally (that is, without going through the TSS), as specified in the NETWORK Block.

Table ACTIVITY, in both the PERLND and RCHRES Blocks, indicates that only water movement is being simulated; no quality constituents are considered in this example. Table PRINT-INFO, also present in both the PERLND and RCHRES Blocks, specifies a print level of 4; that is, printout will occur monthly. Table-type GEN-INFO contains the names of the PLSs and the RCHRESs and, in the latter case, also specifies the number of "exits" (outflows). RCHRES 3 has two exits; one supplies an irrigation demand, the other is for any flow over the spillway.

Tables PWAT-PARM2 and PWAT-PARM4 show that the two PLSs have different parameter sets. However, initial conditions are the same for both (Table PWAT-STATE1).

Table HYDR-PARM1 indicates that, for all three RCHRESs, the outflow demands are functions of stored volume only (ODFVFG >0, ODGTFG =0). Also, for RCHRES 3, flag A1 is ON, which means that auxiliary variables such as depth and surface area will be computed. This is required to calculate the quantity of water supplied to the reservoir by precipitation on the surface and the quantity lost by evaporation (depth*surface area). Table HYDR-PARM2



Reservoir details:

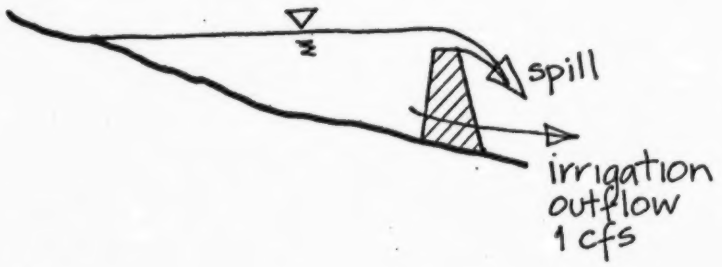


FIGURE 1 System simulated in Example in Section 3.0

indicates that RCHRESs 1 and 2 share a common FTABLE; that is, they have identical hydraulic properties.

The FTABLES Block contains the function tables, which specify the hydraulic properties of each RCHRES. Note that FTABLE 101 has two "discharge" columns, because RCHRES 3 has two exits.

The PLTGEN Block contains the data necessary to generate a "plot file", which will be read by a separate program to plot the inflow and outflow rates for the reservoir. Table PLOTINFO indicates that the plot file is Fortran unit no. 30 and that two point-valued time series are to be plotted (no mean-valued time series). Other tables give the plot labels, scaling information, etc.

The EXT SOURCES Block indicates that member PRECIP of TSS dataset no. 25 is to supply precipitation input for both PLSs and the reservoir, using a different multiplication factor each time. These operations also share the same source of potential ET data (TSS 26).

The NETWORK Block specifies the connectivity of the operations. The outflow from PLS 1 (member PERO of time series group PWATER) becomes inflow to RCHRES 1 (Figure 1). The multiplication factor converts the outflow, in inches/interval, to RCHRES inflow, in acre-ft/interval, and thus includes the tributary area (in acres) and a factor of 12 to change runoff depth from inches to feet. RCHRESs 1 and 2 both flow into RCHRES 3. The outflow rates from RCHRES 1 and 2 are both routed to member POINT 1 of group INPUT for the plot operation. Thus, the sum of these rates will be the first plotted time series. The second plotted time series will be the total outflow rate for RCHRES 3.

```
!JOB COMPRTST,RCJ.P8004
!FILE FTN01=INFOFL.RCJ.P7614,OLD;ACC=IN
!FILE FTN02;REC=-84,3,F,ASCII
!FILE FTN03=ERRFL.RCJ.P7614,OLD;ACC=IN
!FILE FTN04=WARNFL.RCJ.P7614,OLD;ACC=IN
!FILE FTN05=$STDIN
!FILE FTN07;REC=-22,11,F,BINARY
!FILE FTN08;REC=1000,1,F,BINARY
!FILE FTN09;REC=300,1,F,BINARY
!FILE FTN10;REC=300,1,F,BINARY
!FILE FTN12;REC=60,6,F,BINARY
!FILE FTN15=TSSFL.RCJ.P8004,OLD
!PURGE PLOTFL
!BUILD PLOTFL;REC=-80,3,F,ASCII;DISC=1500
!FILE FTN30=PLOTFL,OLD
!SETDUMP
!RUN HSPFPF.USLS.P7614
RUN
```

```
GLOBAL
  Running a network of 2 Land-segments, 2 Rchres's and 1 Plot Operation
  START       1974/06           END    1974/06
  RUN INTERP OUTPUT LEVEL    3
  RESUME     0 RUN     1
END GLOBAL

OPN SEQUENCE
    INGRP               INDELT 00:30
      PERLND        1
      PERLND        2
      RCHRES        1
      RCHRES        2
      RCHRES        3
      PLTGEN        1
    END INGRP
END OPN SEQUENCE

PERLND
  ACTIVITY
    #thru# ATMP SNOW PWAT  SED PSTP PWTG PQAL MSTL PEST NITR PHOS TRAC ***
    1    2    0    0    1
  END ACTIVITY

  PRINT-INFO
    #thru#           PFLAG ***
    1    2              4
  END PRINT-INFO

  GEN-INFO
    #thru#      Name           NBLKS                Printout  ***
    1       Land-segment One       1                   6
    2       Land-segment Two       1                   6
  END GEN-INFO

  TABLES FOR SECTION PWATER ***

  PWAT-PARM1
    #THRU# CSNO RTOP ***
    1    2    0    1
  END PWAT-PARM1

  PWAT-PARM2
    #THRU#*** FOREST      LZSN     INFILT      LSUR      SLSUR      KVARY      AGWRC
    1           0.0       16.0       .50       300.       .24        .00        .99
    2           0.0       20.0       .45       400.       .10        .00        .995
  END PWAT-PARM2

  PWAT-PARM4
    #THRU#***  CEPSC      UZSN      NSUR      INTFW       IRC      LZETP
    1            .25       0.8       .35       3.0        .75       .30
    2            .25       1.0       .35       4.0        .85       .45
  END PWAT-PARM4
```

```
  PWAT-STATE1
    #THRU#***   CEPS      SURS       UZS       IFWS       LZS       AGWS      GWVS
    1    2                           1.2                  24.5       8.5       2.0
  END PWAT-STATE1

END PERLND


RCHRES
  ACTIVITY
    #thru# HYDR ADCA CONS HEAT  SED  FST OXRX NUTR PLNK   PH ***
    1    3    1
  END ACTIVITY

  PRINT-INFO
    #thru#PFLAG ***
    1    3    4
  END PRINT-INFO

  GEN-INFO
    #thru#      Name          NEXITS    Unit flags    Print-files ***
    1      Reach 1               1     1    1    1     6     0
    2      Reach 2               1     1    1    1     6     0
    3      Reach 3(reservoir)    2     1    1    1     6     0
  END GEN-INFO

  HYDR-PARM1
    #thru#              Flags                                    ***
              V  A  A          ODFVFG              ODGTFG        ***
            CON  1  2        1  2  3  4  5        1  2  3  4  5 ***
    1    2                   4
    3              1         4  5
  END HYDR-PARM1

  HYDR-PARM2
    #thru#    FTABNO       LEN ***
    1    2       100       1.0
    3            101       0.1
  END HYDR-PARM2

  HYDR-INIT
    #THRU#       VOL(ac-ft) ***
    3           200.
  END HYDR-INIT

END RCHRES
```

```
FTABLES

  FTABLE     100
  Rows/cols ***
    5    4
     DEPTH      SAREA       VOL      Disch ***
        ft      acres   acre-ft      ft3/s ***
       0.0        0.0       0.0        0.0
       2.0       1.72       3.0       16.0
       6.0       4.44      12.0      106.0
      10.0       14.5      51.0      521.0
      15.0       40.0     200.0     2500.0
  END FTABLE100

  FTABLE     101
  Rows/cols ***
    5    5
     DEPTH      SAREA       VOL      Disch      Disch ***
        ft      acres   acre-ft      ft3/s      ft3/s ***
       0.0        0.0       0.0        1.0        0.0
      10.0        7.5        25.       1.0        0.0
      20.0       30.0       200.       1.0        0.0
      25.0        47.       390.       1.0       100.
      30.0       67.5       675.       1.0      1000.
  END FTABLE101

END FTABLES
```

```
PLTGEN
  PLOTINFO
    #thru# FILE   NPT  NMN Labl ***
    1        30    2
  END PLOTINFO

  GEN-LABELS
    #thru#<-----------------TITLE ----------------->***        <-------Y AXIS------->
    1     Plot of reservoir flowrates                          Flow (ft3/sec)
  END GEN-LABELS

  SCALING
    #thru#       YMIN       YMAX      IVLIN ***
    1                       300.        48.
  END SCALING

  CURV-DATA   (first curve)
    #thru#     < Curve label  > ***
    1          Inflow
  END CURV-DATA

  CURV-DATA   (second curve)
    #thru#     < Curve label  > ***
    1          Outflow
  END CURV-DATA
END PLTGEN

EXT SOURCES
<-Volume-> <Member> SsysSgap<--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name>   # <Name> # tem strg<-factor->strg <Name>   #   #        <Name> # #  ***
TSS      25 PRECIP   METR         1.3        PERLND   1     EXTNL  PREC
TSS      25 PRECIP   METR         1.5        PERLND   2     EXTNL  PREC
TSS      25 PRECIP   METR         1.0        RCHRES   3     EXTNL  PREC
TSS      26 PETDAT   METR                    PERLND   1   2 EXTNL  PETINP
TSS      26 PETDAT   METR                    RCHRES   3     EXTNL  POTEV
END EXT SOURCES

NETWORK
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name>   #        <Name> # #<-factor->strg <Name>   #   #        <Name  # #  ***
PERLND   1 PWATER PERO         53.3        RCHRES   1     EXTNL  IVOL
PERLND   2 PWATER PERO         36.7        RCHRES   1     EXTNL  IVOL
PERLND   2 PWATER PERO         70.0        RCHRES   2     EXTNL  IVOL
RCHRES   1 HYDR   ROVOL                    RCHRES   3     EXTNL  IVOL
RCHRES   2 HYDR   ROVOL                    RCHRES   3     EXTNL  IVOL
RCHRES   1 HYDR   RO                       PLTGEN   1     INPUT  POINT  1
RCHRES   2 HYDR   RO                       PLTGEN   1     INPUT  POINT  1
RCHRES   3 HYDR   RO                       PLTGEN   1     INPUT  POINT  2
END NETWORK

END RUN
!EOD
!EOJ
```